Strategic Inventory Management in an Aerospace Supply Chain

By

Joseph Mauro

Bachelor of Science in Computer Engineering, Tufts University, 1997

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

Master of Business Administration
and
Master of Science in Engineering Systems

In conjunction with the Leaders for Manufacturing Program at the

Massachusetts Institute of Technology

June 2008

Signature of Author_______________
Engineering Systems Division &
MIT Sloan School of Management
May 9, 2008

Certified by____________________
David Simchi-Levi, Thesis Supervisor
Professor of Civil and Environmental Engineering and Engineering Systems

Certified by________
Donald B. Rosenfield, Thesis Supervisor
Director, Leaders for Manufacturing Fellows Program
~~Senior~~ Lecturer, MIT Sloan School of Management

Accepted by____________________
Dr. Richard Larson, Professor of Engineering Systems
Chair, Engineering Systems Division Education Committee

Accepted by____________________
Debbie Berechman
Executive Director of MBA Program, MIT Sloan School of Management

This page has been intentionally left blank

Strategic Inventory Management in an Aerospace Supply Chain

By
Joseph Mauro

Submitted to the MIT Sloan School of Management and the
Engineering Systems Division on May 9, 2008 in Partial Fulfillment of the
Requirements for the Degrees of Master of Business Administration and
Master of Science in Engineering Systems

ABSTRACT

This paper introduces multiple methods to set and optimize inventory levels. These methods are then classified based on the complexity involved to implement them. As an organization develops a deeper understanding of inventory, it becomes more mature and can apply more complex methods. This sequencing of methods is defined as a three phase maturity model. First, a foundational level of maturity is defined, which quantifies inventory levels based on future demand and business requirements. Second, a transitional level of maturity defines safety stock positioning in a single-echelon supply chain. Finally, the maturity model concludes with an optimal level of maturity that is based on principles of multi-echelon inventory optimization: safety stock at multiple positions of a supply chain.

The setting for this paper was the Aerospace industry. Honeywell Aerospace is in the middle of a 3-year effort to re-engineer Sales, Inventory and Operations Planning (SIOP) systems. At the same time, Honeywell Aerospace is standardizing on a uniform implementation of an ERP system. Through SIOP, standard inventory and planning practices aided by the uniform ERP backbone and a strategic inventory program executive management hopes to reduce what is seen as a disproportionate contribution of inventory to Honeywell International.

Thesis Supervisor: David Simchi-Levi
Title: Professor of Civil and Environmental Engineering and Engineering Systems

Thesis Supervisor: Donald B. Rosenfield
Title: Director, Leaders for Manufacturing Fellows Program
Senior Lecturer, MIT Sloan School of Management

This page has been intentionally left blank

Acknowledgments

I would like to thank Honeywell Aerospace, and especially LFM alumnus Mitch Malone, for sponsoring this internship. Mitch, on behalf of Honeywell, has always put together great open-ended challenges that benefit the LFM intern and deliver business impact for Honeywell. Thank you Mitch! Thanks also go to Seema Phull, who served as my Executive Sponsor. Seema always made sure that my work had business impact and support from its customers.

This thesis could not have been possible without the assistance of two supply chain gurus in my advisors: Don Rosenfield and David Simchi-Levi.

I would also like to thank Geoff DeCarbonnel. Geoff was always very eager to envelop himself in an inventory challenge and lend a helping hand. A number of the frameworks in this paper would not have been possible without Geoff's assistance. He stressed the importance of frameworks as a means to presenting the critical factors to the user community – thus simplifying the message without losing the pertinent elements.

A very big thank you also goes to Maggie LaRocca and Colby McCullough. Colby and Maggie treated me as more than an intern – as a member of their team. Colby was always more than happy to jump in front of a whiteboard or a monitor and tackle a problem with me. Maggie was a big help in keeping my effort aligned with Honeywell Aerospace initiatives, and pushing me when a push was needed.

Todd Gregson and Steve Hoeland were a big help in the Phoenix Engines proof of concept. Not only were they critical users of my work, with plenty of suggestions but they also provided a great approach to challenges – a positive attitude. Sandra Rogers, Liz Collazo and Cynthia Grosso made the Tempe proof of concept possible and Dan Graf and Scott Boroff provided data that made the APC Deer Valley analysis possible. Thank you to all of you!

There are many other people at Honeywell that I would like to thank: Craig Bodnar, Sabrina Chang, Todd Cooper, Andrea Horst, Geoff Hubbell, Ben Lathrop, Kim Murdoch, Mike Parkins, Nick Purzer and Chip Zaenglein.

David Margetts – There is a big benefit to having another LFM intern at the same company for the occasional brainstorming session.

I would like to thank my wife, Katherine, for her continued encouragement during LFM. This would have not been possible without her support. And, finally, I would like to thank my family and my in-laws for their support during my time at LFM.

Joseph Mauro
Cambridge, MA
May 2008

This page has been intentionally left blank

Biographical Note

Joseph Mauro was born in Boston, Massachusetts. He attended Tufts University, where he majored in Computer Engineering, graduating with high honors. Joseph worked as a member of the Technical Staff, Computer Hardware, at Sun Microsystems, where he held many positions on the Application Specific Integrated Circuit (ASIC) design team located in Chelmsford, MA and later in Burlington, MA. Seeking new challenges and an opportunity to broaden his exposure to product operations, he accepted an international assignment with Sun's newly opened Asia Operations office located in Hong Kong SAR, China. While based in Hong Kong, Joseph saw firsthand multiple tiers of Sun's supply base. He introduced numerous new products into Asia-based suppliers, developed Sun's Asian supply base and developed concurrent engineering practices.

Joseph enjoys travel, running, cooking and spending time with his family. He is currently learning to sail and windsurf.

He can be contacted via email at joseph.mauro@sloan.mit.edu.

Note on Proprietary Information

In the interest of protecting Honeywell International's competitive and proprietary information, all figures and data presented in this thesis have been changed, are for the purpose of example only, and do not represent actual Honeywell data.

This page has been intentionally left blank

Table of Contents

Table of Figures

Table of Tables

This page has been intentionally left blank

1. Part I: Introduction & Background

1.1. Introduction

The content of this paper was developed during a 6-month internship in the Central Planning and Asset Management (CPAM) group at Honeywell Aerospace. CPAM is responsible for re-engineering Honeywell Aerospace's Sales, Inventory and Operations Planning (SIOP) processes with the goal of better aligning forecasted demand with production capability. The goal of the internship was to create a maturity model, which is a collection of capabilities that describe certain aspects of maturity in an organization, to develop Aerospace's inventory and planning processes, in support of Honeywell's strategic inventory initiative under the SIOP re-engineering effort.

This paper presents the maturity model planned and implemented during the internship period for inventory and planning processes. Part I examines the challenges facing Honeywell Aerospace and discusses research that provides insight into possible solutions. Part II introduces a method for developing inventory and planning process along the dimensions of people, process and technology. Part III, looks at the implementation of the maturity model in various product centers at Honeywell Aerospace. Part IV presents conclusions and recommendations for future work.

1.2. Honeywell Aerospace

Honeywell Aerospace is one of four segments of Honeywell International (NYSE: HON), a diversified technology and manufacturing company that is a member of the Dow Jones Industrial Average. Honeywell Aerospace has traditionally been the largest segment of Honeywell International. But in 2007, for the first time, Aerospace's revenue was surpassed by the Automation and Control System segment. However, it should be noted that Aerospace still contributed the most profit to the parent organization in that period (Honeywell International Inc, 2008).

Honeywell Aerospace is a supplier to aircraft manufacturers, aircraft operators, airlines, military services, and defense and space contractors. Honeywell Aerospace manufactures a diverse set of products such as aircraft engines, avionics, environmental control systems, aircraft wheels and brakes. (Honeywell International Inc, 2008)

Honeywell Aerospace is organized as a matrix with product centers managing the supply chain and business units managing customers. There are four product centers (PCs): (1) Automated Aircraft Landing Systems (AALS), (2) Avionics Product Centers (APC), (3) Engines and Product Centers (EPC) and (4) Guidance and Electric Systems (GES). The product centers are responsible for integrating the supply chain and delivering products to three business units (BUs): (1) Air Transport Region (ATR), (2) Business and General Aviation (BGA) and (3) Defense and Space (D&S).

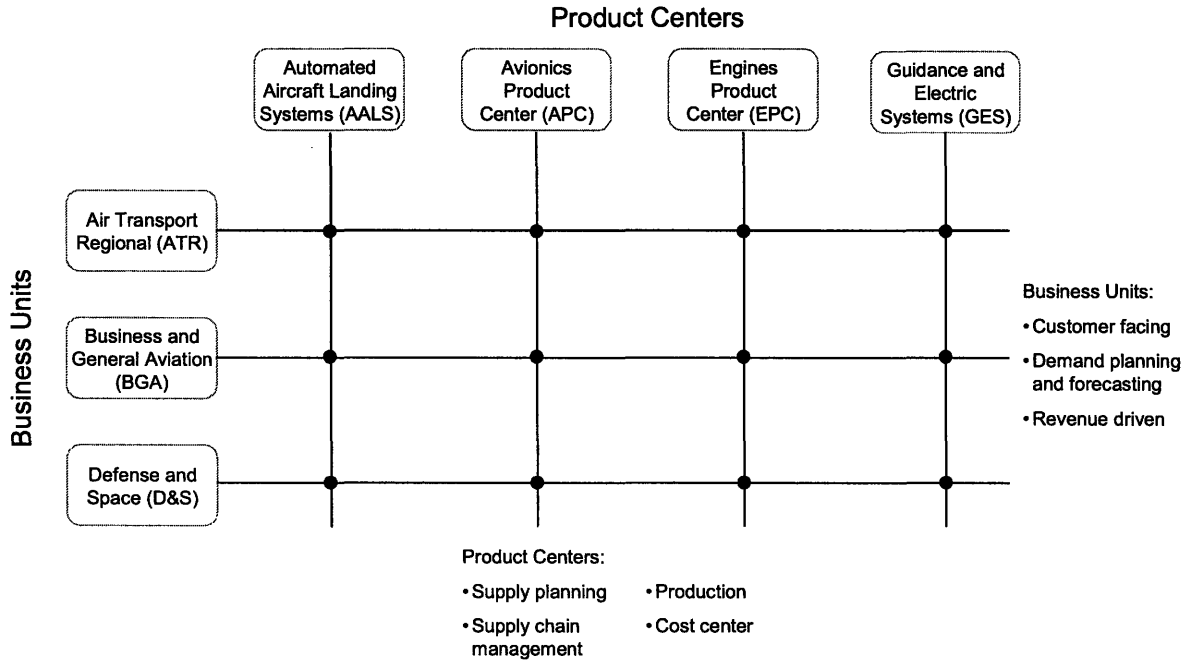


Figure 1: Honeywell Aerospace Organizational Matrix

An example supply chain for an aircraft engine is shown in Figure 2. In this example, Honeywell Aerospace is shown three echelons upstream of the ultimate demand driver, the customer.

Figure 2: Typical Supply Chain for an Aircraft Engine

Figure 3 shows an example supply chain for an avionics product that is sold directly to aircraft operators. In this example, Honeywell Aerospace is two echelons removed from the end user.

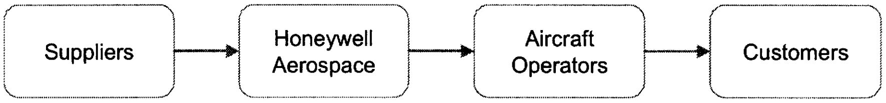


Figure 3: Typical Supply Chain for an Avionics Product

Honeywell Aerospace is a collection of acquisitions and homegrown businesses. This has meant there are a number of different Material Requirements Planning/Enterprise Resource Planning systems and different inventory and planning approaches. Today, Honeywell Aerospace is adopting SAP ERP R/5 across all sites in order to standardize the resource planning backbone, while the CPAM organization is standardizing inventory and planning practices.

1.3. Central Planning and Asset Management (CPAM)

Central Planning and Asset Management manages the planning process, which includes customer demand management, strategic inventory management, replenishment/sourcing models and material planning systems. (For all intents and purposes "asset" at Honeywell means inventory.) The CPAM team owns processes. It is a central, administrative organization. Products, on the other hand, are owned by the Planning and Asset Management (PAM) teams within the four Product Centers.

CPAM is in the middle of a multi-year effort to design, implement, and orchestrate a Sales, Inventory and Operations Planning (SIOP) process. The objective of SIOP is to align long-term demand forecasting with production capability, with the ultimate goal of improving working capital performance.

1.3.1. Sales Inventory and Operations Planning (SIOP) Initiative

Sales, Inventory and Operations Planning is an initiative across all of Honeywell International. Within Honeywell Aerospace, Central Planning and Asset Management is responsible for coordinating the SIOP implementation with the PCs and BUs.

SIOP has brought increased focus on strategic inventory management at Honeywell Aerospace, and is an important backdrop for this internship. Figure 4 captures the main elements of Honeywell Aerospace's SIOP implementation. Typically companies call their sales and inventory initiatives SOP, with the "I" ominously missing. Honeywell, on the other hand, specifically includes *inventory* in its deployment of sales and operations planning emphasizing the importance of inventory.

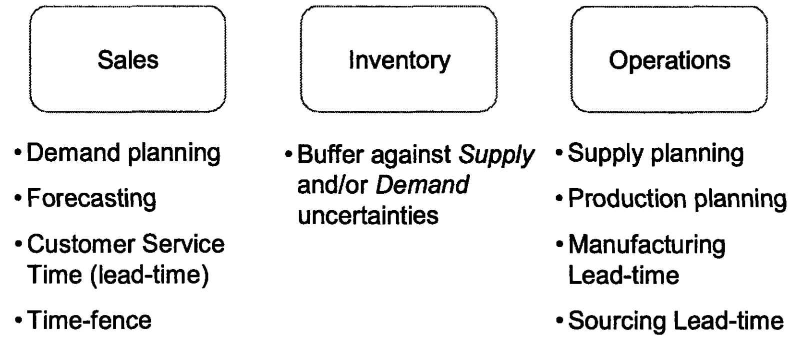


Figure 4: Key Elements of Sales, Operations and Inventory in a SIOP Process

1.3.2. Strategic Inventory

Strategic inventory management is the name given to initiatives that focus on the inventory and planning processes at Honeywell Aerospace. Specifically, the word *strategic* is used to denote that the initiatives are being driven by executive management in a top down fashion. CPAM, who executes strategic inventory initiatives, interfaces with the product center inventory managers. It is at this level in the organizational hierarchy that the internship was targeted.

Historically strategic inventory had its own set of initiatives focused on improving working capital. However, with the increased focus on SIOP, strategic inventory is now structured as an initiative under the deployment of SIOP. This re-organization makes sense in that inventory is a result of the SIOP process. For example, if demand increases within the cumulative manufacturing lead-time, then inventory will increase since safety stock will be required to meet demand.

At one level strategic inventory addresses the tradeoff between aggregate inventory and service level, which is typically referred to as the inventory – service level tradeoff curve as shown in Figure 5. However in order to affect Honeywell Aerospace's performance on the curve it is often necessary, as will be discussed, to initiate projects at the product or product family level.

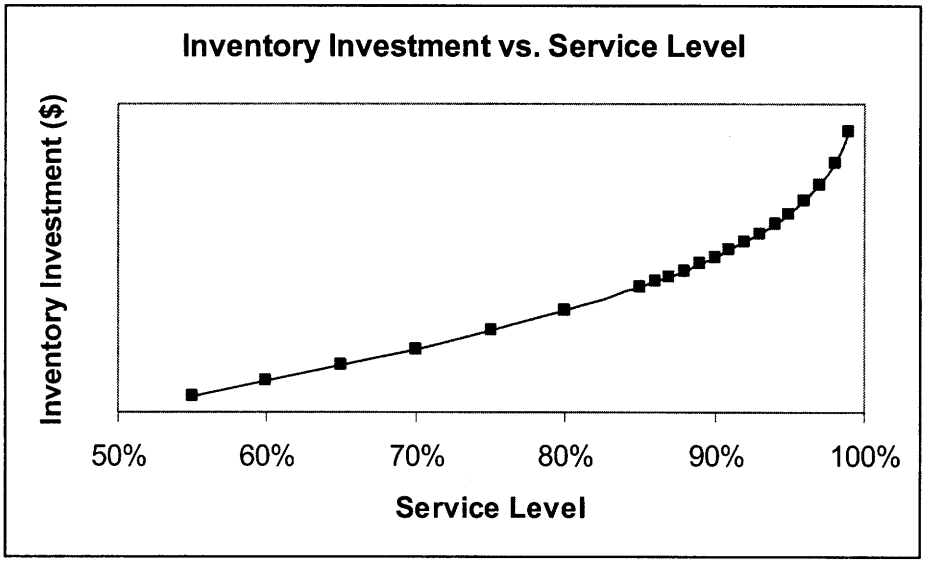


Figure 5: The Inventory – Service Level Tradeoff Curve

In the past, CPAM has focused on multi-echelon inventory optimization projects. But these projects have had limited success, due to a lack of widespread comprehension of the analysis, so the effort of this internship and thus this paper was shifted early on to creating a development path – a journey – that organizations could follow to increase their understanding of inventory causes and effects and to identify and share inventory and planning best practices. Thus was born the need for a so-called maturity model for inventory and planning practices.

1.4. Research

This section covers background research, related to multiple aspects of the Inventory Management Maturity Model introduced in Part 2, and serves as a review of related inventory management literature.

1.4.1. Planning and Execution Strategies

1.4.1.1. MRP

MRP "is a technique to calculate requirements for materials used in production" (Aiello, 2008). MRP systems use a product's bill of material and material lead-times to plan when manufacturing for a particular product should start. MRP systems do not typically take production capacities into consideration, sometimes propose impossible schedules (Simchi-Levi, Kaminsky, & Simchi-Levi, 2003) and are subject to nervousness.

MRP assumes that part lead-times are fixed so that it can reverse calculate releases from due dates. The fixed lead-times are simply a function of the part and do not take into account the loading of the plant. MRP systems assume that parts always take the same amount of time to flow through the plant whether the plant is overloaded or sitting empty. But the time for a part to flow through a plant does depend on the loading of the plant, unless there is infinite capacity. So the fixed lead-time assumption is an approximation of reality that can cause havoc. For example, if jobs are released late, then the downstream assembly of parts can be late. This provides an incentive to inflate part lead-times, entered into the MRP system, to provide a buffer against factory issues, e.g. waiting for resources, machine downtime, quality issues, etc. "But inflating lead-times lets more work into the plant, increases congestion and increases the flow time through the plant which results in more pressure to increase lead-times." (W. J. Hopp & Spearman, 2001).

Hopp and Spearman (2001) also explain how MRP systems are subject to nervousness, "when a small change in the master production schedule results in a large change in planned order releases" (W. J. Hopp & Spearman, 2001). The resulting, unusual behavior is that there is a possibility that a decrease in demand can cause a previously feasible production plan to become infeasible (W. J. Hopp & Spearman, 2001). For an extensive discussion of remedies for nervousness see Hopp and Spearman (2001).

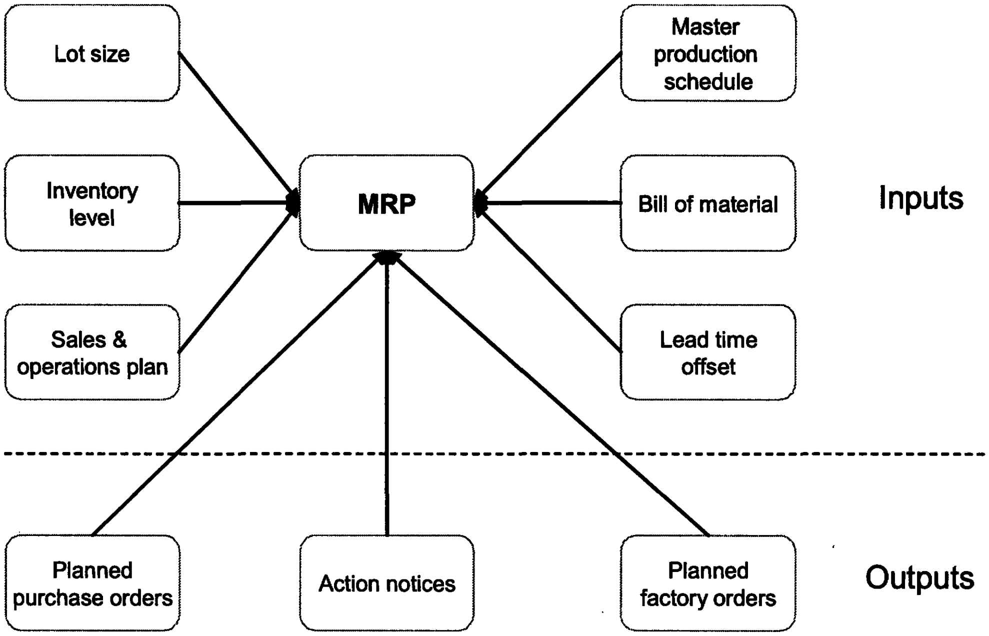


Figure 6: Key Inputs and Outputs of an MRP System (Aiello, 2008)

But, what is relevant to this discussion is how MRP copes with uncertainty. In non-MRP environments, uncertainty is accounted for by using safety stocks. However, in an MRP environment demand is dependent, so safety stocks may not be appropriate. Rather, inventories can be managed (to avoid shortages and excess inventories) by expediting, i.e. adjusting lead-times. (Silver, Pyke, & Peterson, 1998)

However, in MRP systems the complete elimination of safety stocks or safety lead-time for dependent demand items is not a good solution. (Silver et al., 1998) Whybark and Williams (1976) analyzed safety stocks and safety lead-time under four different uncertainty situations:

1. Supply timing: orders not received when scheduled
2. Supply quantity: orders received for more or less than planned
3. Demand timing: requirements shift from one period to another
4. Demand quantity: requirements for more or less than planned

They found that sources involving timing uncertainty, 1 and 3, are best protected by safety lead-time, while sources involving quantity uncertainty, 2 and 4, are best handled by safety stock through a largely qualitative analysis (Whybark, 1976).

Silver et al. (1998) claim that a quantitative analysis of exactly how much safety stock or safety lead-time is appropriate for each situation is extremely complicated due to the "erratic, time-varying, dependent nature of the demand patterns." They suggest the guidelines in Table 1 (Silver et al., 1998).

Safety stock	**Safety lead-time**
• In items with direct external usage • In items produced by a process with a significantly variable yield • In items produced at a bottleneck operation • In certain sub-assemblies used for a myriad of end-items	• In raw materials

Table 1: Safety Stock and Lead-time Guidelines

Vollmann et al. (1997) suggest that safety stock and safety lead-time can be used to protect against demand quantity, demand timing, production timing and production quantities. They suggest that safety stock should be used to protect against uncertainties in quantity, production and/or demand, and safety lead-time be used to protect against uncertainties in timing, production and/or demand (Vollmann, Berry, & Whybark, 1997).

1.4.1.1.1. Push

Hopp and Spearman define a push production system as one that has no explicit limit on the amount of work in process (W. J. Hopp, Spearman, Mark L., 2004). Material Requirements Planning (MRP) is a push system, according to Hopp and Spearman, because there is no bound on the amount of work in process. MRP releases orders according to a master production schedule without regard to the status of the system (W. J. Hopp, Spearman, Mark L., 2004).

1.4.1.2. Pull

A push strategy is often contrasted with a pull strategy. Hopp and Spearman define a pull production system as one that "explicitly limits the amount of work in process that can be in a system" (W. J. Hopp, Spearman, Mark L., 2004). The more common definition of pull is a system where production is coordinated by true customer demand (Simchi-Levi et al., 2003).

1.4.1.3. Push-Pull Systems

In a push-pull system some echelons of the supply chain, typically the upstream ones, operate by a push-system while some echelons of the supply chain, usually the downstream ones, operate by a pull-system. The push-pull boundary is the name given to the interface between the push-system and the pull-system (Simchi-Levi et al., 2003).

1.4.2. Uncertainty

Uncertainty in operations environments comes in many forms. The classification used in this paper is forecasting, consumption and supply uncertainty. A discussion of each, including examples, follows.

1.4.2.1. Forecasting

A forecast is an estimation of an unknown situation. Forecasting uncertainty or error, then, is the variation between a forecast and the actual usage or consumption.

1.4.2.2. Consumption

Consumption is the amount of goods used, or consumed, by a downstream process. Consumption uncertainty is defined as the variation of consumption over time. The difference between forecast error and consumption uncertainty is that forecast error also includes forecast bias, which is the long-run difference between the forecast and mean usage or consumption.

1.4.2.3. Supply

Supply uncertainty includes variation in production timing and production quantities. Production timing issues are due to machine breakdowns, quality problems, fluctuations in staffing, etc. On the other hand, production quantity issues are due to yield loss or fallout – anything that causes a discrepancy between the number of good parts that finish, and the quantity that start.

Depending on the point of reference, supply uncertainty can also include variation in supply timing and supply quantities from upstream suppliers. Supply timing issues include production timing issues (cited above), and adds transportation timing issues. Supply quantity issues are differences between ordered and received quantities from upstream suppliers.

1.4.3. Sales and Operations Planning

The American Production and Inventory Control Society (APICS) define Sales and Operations Planning as:

> A process that provides management the ability to strategically direct its businesses to achieve competitive advantage on a continuous basis by integrating customer-focused marketing plans for new and existing products with the management of the supply chain. The process brings together all the plans for the business (sales, marketing, development, manufacturing, sourcing, and financial) into one integrated set of plans. It is performed at least once a month and is reviewed by the management team at an aggregate (product family) level. The process must reconcile all supply, demand, and new product plans at both the detail and aggregate level and tie to the business plan. It is the definitive statement of the company's plans for the near to intermediate term covering a horizon sufficient to plan for resources and to support the annual business planning process. Executed properly, the sales and operations planning process links the strategic plans for the business with its execution and reviews performance measures for continuous improvement. (Cox, Blackstone, & APICS--The Educational Society for Resource Management., 2002)

In other words, Sales and Operations Planning serves to balance supply (what is purchased and made) with demand (forecast and actual orders) (Aiello, 2008).

1.4.4. Safety Stock Equations

Safety stock equations come in two forms: one form based on a single source of variability, for example demand, as shown in Figure 7, and a second form based on both demand and supply variability as shown in Figure 8.

$$ss = z\sigma\sqrt{L_e}$$

Where:

ss = Safety stock

z = z factor for the corresponding service level

L_e = Echelon lead time, defined as the lead-time between the 1st echelon and the 2nd echelon plus the lead time between the 2nd echelon and its supplier, assuming inventory is not kept at the 2nd echelon. In general, it is the lead-time to the next location where safety stock is held.

σ = Standard deviation of (aggregate) demand across all customers of a given item

Figure 7: Safety Stock Equation (Simchi-Levi et al., 2003)

$$ss = z\sqrt{\mu_{lt}\sigma_d^2 + \mu_d^2\sigma_{lt}^2}$$

Where:

ss = Safety stock

z = z factor for the corresponding service level

μ_{lt} = average lead-time

σ_d = standard deviation of demand

μ_d = average demand

σ_{lt} = standard deviation of lead-time

Figure 8: Safety Stock Equation with Demand and Supply Variability (Simchi-Levi et al., 2003)

1.4.5. Multi-Echelon Inventory Optimization

Graves and Willems (1996) developed a framework for modeling strategic safety stock in a supply chain that is subject to demand or forecast uncertainty. They assumed that they could model the supply chain as a network, that each stage in the supply chain operates with a periodic-review base-stock policy, that demand is bounded, and that there is a guaranteed service time between every stage and its customers. They then developed an optimization algorithm for the placement of strategic safety stock for supply chains that can be modeled as spanning trees (S. C. Graves, and S. P. Willems, 2000).

The optimization model determines where to place decoupling inventories to protect one part of the supply chain from another. A decoupling safety stock is an inventory that is large enough to allow downstream echelons of the supply chain to operate independently from upstream echelons. Since the model analyzes the entire supply chain, i.e. multiple echelons, and determines where to place these decoupling buffers, it is considered "strategic" in nature and commonly called the strategic inventory placement model. (S. C. Graves, and S. P. Willems, 2000).

This algorithm ultimately led to the founding of Optiant Inc. in 2000, and soon thereafter became the basis for the PowerChain Inventory software application. PowerChain optimizes inventory targets in order to reduce overall inventory cost, while increasing customer service levels. The PowerChain application delivers increased customer satisfaction, a more efficient use of capital, and a supply chain that copes with supply and demand uncertainty. Inventory levels are determined by considering supply and demand uncertainty, while inventory locations are determined by balancing cost and lead-time considerations (S. C. Graves, and S. P. Willems, 2000). For a more extensive review of the mathematics behind the algorithm see Willems (1996) and Willems (1999).

Related to Graves and Willems' work (2000) are numerous papers on multi-stage inventory models with uncertain demand. Simpson (1958) determined optimal safety stocks for a supply chain modeled as a serial network. Inderfurth (1991, 1993), Inderfurth and Minner (1998), and Minner (1997) built off of Simpson's framework for optimizing safety stocks in a supply chain. Graves and Willems (2000) extend these works by modeling the supply chain as a spanning tree network.

Also related to Graves and Willems' work (2000) are numerous papers such as Lee and Billington (1993), Glasserman and Tayur (1995), and Ettl et al (2000), which examine the determination of the optimal base-stock levels in a supply chain in a way that is applicable to practice. Graves and Willems' work (2000) is similar in that it also assumes base-stock policies, and focuses on minimizing the requirements in a supply chain. However, Graves and Willems (2000) make different assumptions about the demand process and apply different constraints on service levels within the supply chain (S. C. Graves, and S. P. Willems, 2000).

1.4.6. Maturity Models

A maturity model is a standard nomenclature given to a collection of practices that describe certain aspects of maturity in an organization. Maturity models can help establish a common vision and they may establish and prioritize activities or practices that create a roadmap for an organization to attain that vision. At a very basic level, maturity models help to create a common language. There is a number of maturity models used in different areas. For example, Carnegie Mellon created the Capability Maturity Model (CMM), which is a process capability maturity model that describes the "characteristics" of effective processes, specifically for software development processes. The CMM defines five maturity levels, providing a progression in continuous improvement for an organization: initial, repeatable, defined, managed and optimized (CMU SEI, 2007).

The CMM has been superseded by the Capability Maturity Model Integration (CMMI), which is broken into a development model for product and service development processes, and an acquisition model for outsourcing processes. CMMI, similar to CMM, is a process improvement approach that provides organizations with the essential elements of effective processes (CMU SEI, 2008). CMMI can be used to guide process improvement by setting process improvement goals and priorities, and providing a reference point for appraising current processes. The CMMI defines a process maturity profile which also consists of five levels: initial, managed, defined, quantitatively managed and optimizing (CMU SEI, 2007).

In *The Process Audit* Michael Hammer defines a Process and Enterprise Maturity Model, PEMM, which provides a development path so that an organization's business processes can become more mature. He describes five process enablers (design, performers, owner, infrastructure and metrics) and four enterprise capabilities (leadership, culture, expertise and governance). Organizations can use the evaluations of the enablers and capabilities to plan and assess the progress of process-based transformations. Progress is measured against four levels to determine where an organization's capabilities stand (Hammer, 2007).

PEMM differs from the CMMI, or CMM for that matter, because it applies to companies in any industry and does not specify what a particular process should look like. CMMI applies specifically to software development and acquisition(s). The CMMI compares an organization's processes against process best practices to determine the organization's maturity. On the other hand, PEMM "identifies the characteristics that any process and every enterprise should have in order to design and deploy high performance processes" (Hammer, 2007).

1.4.7. People, Process & Technology Framework

The people, process and technology framework is a popular approach when analyzing problems, or developing processes from a multi-dimensional perspective. The framework is largely ubiquitous, and is found in many papers and books.

In 2006, James Morgan and Jeffrey Liker published *The Toyota Production Development System: Integrating People, Process and Technology*, a comprehensive analysis of how Toyota designs and builds automobiles. Morgan and Liker analyzed Toyota's production development system, and argued for the "importance of appropriately integrating people, process, tools and technology to add value to the customer" (Morgan & Liker, 2006).

Process, skilled people, and tools and technology are the three subsystems that form the Toyota Production Development System. The process subsystem is concerned with all the tasks and sequence of tasks necessary to bring a product from concept to start of production. Next, the people subsystem covers the organization's shared language, symbols, beliefs and values – the elusive things known as a company's "culture". Finally, the tools and technology subsystem includes not only the computer software systems but also tools that support the effort of people (Morgan & Liker, 2006).

2. Part II: Methodology

2.1. Introduction to the Inventory Management Maturity Model

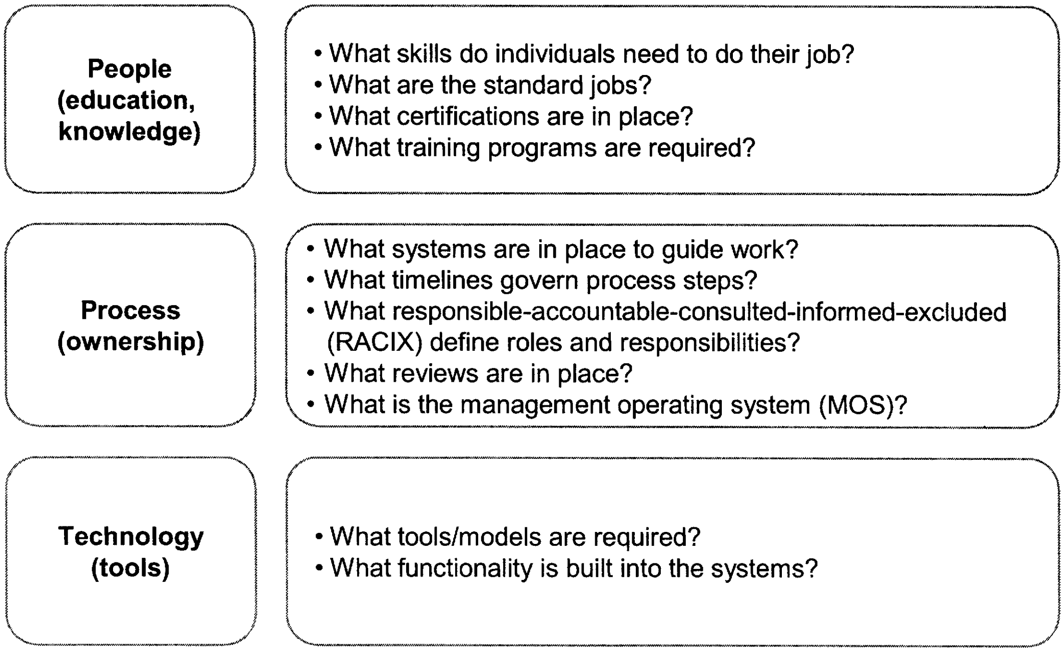
A maturity model for inventory and planning practices was created to serve as a development framework for the Planning and Asset Organizations within Honeywell Aerospace. There are clear benefits to a documented maturity model. Firstly, it provides a starting point for development. Secondly, a maturity model establishes a development path. Thirdly, a maturity model can be a framework for organizational improvement. Finally, a maturity model can establish a common language and a shared vision.

The approach of using a maturity model was taken for a number of reasons. Historically, Honeywell Aerospace had tried to implement the cutting edge in inventory practice, multi-echelon inventory optimization. These efforts were met with limited success. In reviewing past implementation attempts, we decided that the organization needed to develop a foundation in inventory knowledge rather than "jumping" into what is considered best practice(s). Secondly, Honeywell's Aerospace culture was accustomed to discussing maturity of organizations and practices, yet when it came to inventory there was no documented prior standard for maturity.

The maturity model developed for Honeywell Aerospace was called the Inventory Management Maturity Model. For convenience sake, it was referred to as IM^3. The model consisted of a three dimensional framework of people, process and technology and defined maturity along three phases: foundational, rightsizing and optimization.

2.1.1. People, Process & Technology Framework

Figure 9 shows the framework used for the Inventory Management Maturity Model: People, Process and Technology. "People" refers to the knowledge that individuals should possess at each stage of maturity. This knowledge can be demonstrated by certifications, completed training programs and required skills. The second element of the framework is Process. "Process" governs aspects of processes that are necessary to make them robust: timelines, roles and responsibilities and management reviews. The final element of the IM^3 framework is Technology. “Technology” refers to the tools that are necessary to support the phase of maturity.



People (education, knowledge)

- What skills do individuals need to do their job?
- What are the standard jobs?
- What certifications are in place?
- What training programs are required?

Process (ownership)

- What systems are in place to guide work?
- What timelines govern process steps?
- What responsible-accountable-consulted-informed-excluded (RACIX) define roles and responsibilities?
- What reviews are in place?
- What is the management operating system (MOS)?

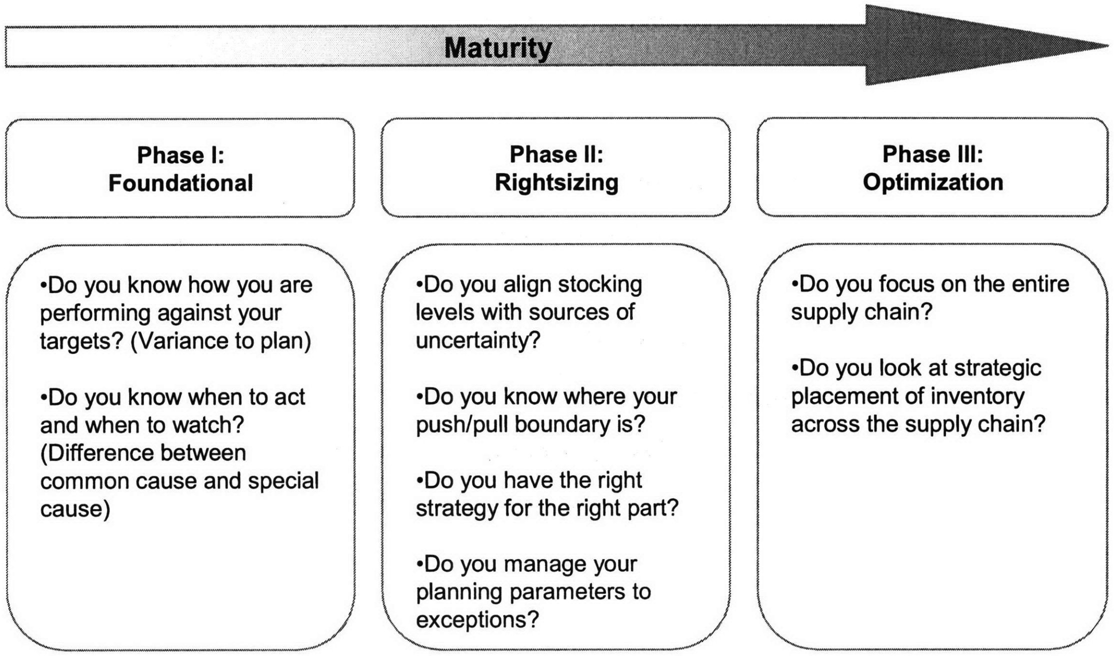
Technology (tools)

- What tools/models are required?
- What functionality is built into the systems?

Figure 9: IM^3 People, Process & Technology Framework

2.1.2. Phases of Maturity

The Inventory Management Maturity Model was created with three distinct stages, called phases of maturity: foundational, rightsizing and optimization. Phase I, the foundational stage, describes practices that are at a basic level, when a site should know its current inventory performance, and how much its performance varies against its planned performance. Also at phase I, a site should have sufficient understanding of the difference between common and special cause events, and how they affect inventory.



Phase I: Foundational

- Do you know how you are performing against your targets? (Variance to plan)
- Do you know when to act and when to watch? (Difference between common cause and special cause)

Phase II: Rightsizing

- Do you align stocking levels with sources of uncertainty?
- Do you know where your push/pull boundary is?
- Do you have the right strategy for the right part?
- Do you manage your planning parameters to exceptions?

Phase III: Optimization

- Do you focus on the entire supply chain?
- Do you look at strategic placement of inventory across the supply chain?

Figure 10: IM^3 Phases of Maturity

Phase II is called the rightsizing phase. Broadly speaking, at this stage a site should be calculating safety stock levels using traditional single echelon methods. In other words, the site uses a reasonable level of sophistication including statistical analysis to align stocking levels with sources of uncertainty. And the site establishes its production planning strategy (pull, make-to-stock, make-to-order) based on manufacturing lead-times and customer service times. Since phase II encompasses production planning strategies the concept of push/pull boundary is relevant. Finally, from a management perspective phase II shifts to a manage-by-exception approach.

Phase III is the optimization phase where a site should be applying multi-echelon inventory concepts to calculate stocking levels. During phase III the scope of focus is also expanded beyond the four walls of a site to encompass the full supply chain, both upstream to suppliers and downstream to customers.

A maturity model was chosen to create a development path for inventory and planning practices at Honeywell for a number of reasons. First, Honeywell culture embraces maturity when reviewing performance. Maturity is common to Honeywell's business lexicon. Secondly, Honeywell is developing maturity models for various processes within supply chain management, including (1) demand planning, (2) distribution planning and replenishment, (3) order management and fulfillment and (4) sales and operations planning. Central Planning and Asset Management sought to supplement this effort with a maturity model for inventory and planning processes.

The inventory management maturity model was constructed with three phases of maturity based on discussions with stakeholders. Three phases provided enough differentiation among sites while, at the same time, laying out a path to develop capabilities. While there is no evidence supporting the effectiveness of a three phase maturity model, this paper applies methods from the first two phases of the maturity model to demonstrate that these methods can improve the inventory and planning capabilities of organizations.

2.2. Phase I: Foundational

At a high level, phase I maturity means that a site should know what its inventory level should be, given its planning parameters and commitments to future business. Phase I maturity defines a basic or foundational state in terms of people, process and technology. Planning parameters captured in systems reflect actual practice; any hidden factory is exposed. The emphasis of inventory projects should be on variance to inventory entitlement, and business inventories are quantified to allow for cross-functional inventory projects.

2.2.1. People

Along the people framework, phase I maturity means that people have a demonstrated understanding of key components of inventory cause and the planning parameters that drive them. Individuals should know the different classifications of inventory, and understand the purpose of each classification. Finally, people should be able to demonstrate an understanding of key planning approaches such as push and pull.

2.2.2. Process

For phase I process maturity, a site should be setting inventory targets based on the planning parameters captured in the systems. It should be clear who is responsible for setting system planning parameters. Next, each part should have a clearly defined strategy that is applied in the production environment. There should be a periodic review to examine system planning parameters. Finally, a process to review a site's variance to its entitled inventory levels should be in place.

2.2.3. Technology

The technology framework addresses tools and systems. For foundational, phase I, maturity the system planning parameters should be understood. Most importantly, an Inventory Entitlement Model, which produces a standard report and can show variance to actual inventory levels, should be in place.

2.2.4. Inventory Entitlement Model

An Inventory Entitlement Model captures the inventory a site should have – based on planning parameters (inventory order policy and demand plan) captured in systems and decisions made to support future business. This calculated inventory level is not necessarily optimal: it is a result of implemented planning parameters and business agreements with internal and external customers.

The Inventory Entitlement model includes a provision for safety stock but the safety stock levels input into the model are based on figures captured in planning systems. These levels do not necessarily best protect against uncertainty and are often automatically calculated without user input or set arbitrarily by planners. (More importantly, these levels contrast sharply with the levels that will be calculated, through the seven step process, in phase II of the maturity model.)

2.2.4.1. Objective

The objective of the model is to provide a manufacturing site with an inventory number that it can achieve if all activities (procurement, manufacturing and fulfillment) were executed to plan.

The plan is based on planning parameters and future demand that are captured within planning systems and commitments to other business stakeholders.

The model is not meant to provide a statistically accurate nor optimal inventory level. Since the model is used for phase I maturity, the foundational stage, the emphasis is, instead, on an operational model – something that is usable, actionable and easy to compile. The model provides for comparisons between actual inventory performance and targeted inventory with the hope of distinguishing between causes that are due to process design and execution. To facilitate these comparisons and focus inventory projects on the correct stakeholders, the model classifies inventory into two categories: site operating inventory and business inventory.

2.2.4.2. Site Operating Inventory

Site operating inventory is defined as stock directly related to usual production. It is the active inventory: the stock that is regularly replenished, transformed into finished product and shipped to customers to address ongoing demand. This inventory is typically classified into raw material, work in process and finished goods inventory.

Site operating inventory differs from business inventory. The ownership for site operating inventory lies with a company's operations group. This group may be influenced by other stakeholders, but ultimately the operations group procures the material, schedules production and fulfills customer orders. There is no shared responsibility for site operating inventory. But business inventory, on the other hand, has a shared ownership between the operations group and another business function such as sales or marketing.

Issues causing a variance between entitled and actual site operating inventory can take two broad forms: relating to process design or execution. Design problems cause planning processes to consistently miss entitlement targets, while execution problems lie with the implementation of the process. Entitled inventory is calculated from two system sources: inventory order policies and future demand.

2.2.4.2.1. Raw Material

The raw material category includes all purchased parts. The entitlement is a function of the inventory order policy and the future demand for the associated finished goods. The order policy is specified in terms of days of supply (DOS) and not in units (for example, 5 DOS means 5 days of inventory). Thus it is possible and likely that the order policy for a given part may change in terms of units while staying consistent in terms of days of supply.

The entitlement is calculated on a monthly basis, and is the average inventory level, or the expected inventory at any time. In other words, the raw material entitlement is equal to the sum of the safety stock and average cycle stock. Safety stock, may include safety lead-time (converted to a stock from a time). Typically Honeywell sites primarily employ safety lead-time instead of safety stock. A graphical representation of the entitlement for a purchased part is given in Figure 11.

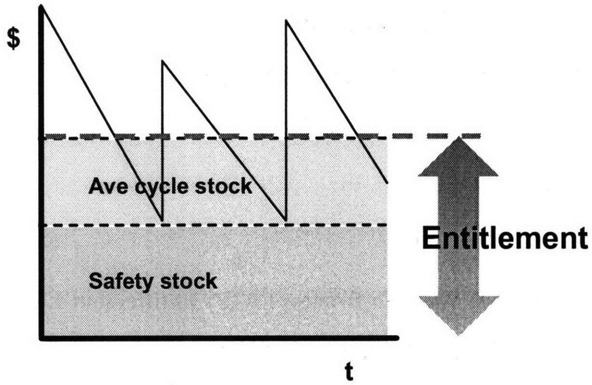


Figure 11: Raw Material Entitlement Level

Some purchased parts are not procured through MRP, but instead are managed using a kanban system with suppliers. In these instances where the supplier receives a pull signal, the entitlement is calculated as the expected inventory level plus any safety stock.

2.2.4.2.2. Work in Process (WIP)

Work in process (WIP) is the term given to inventory that is transformed from raw material into a finished good. The entitlement is a function of the transformation cycle time, the future demand for the finished good and the amount of value added to the raw material cost. For the purposes of the inventory model, labor and overhead were assumed to be applied in a linear fashion to the cost of the raw material as illustrated in Figure 12.

The entitlement target is calculated on a monthly basis and equals the average inventory level or the expected inventory at any time. In most cases, Honeywell does not hold inventory of semi-finished goods but converts all raw materials directly into finished goods. However, in cases where semi-finished goods are stocked, a provision is made to include the average inventory in stores.

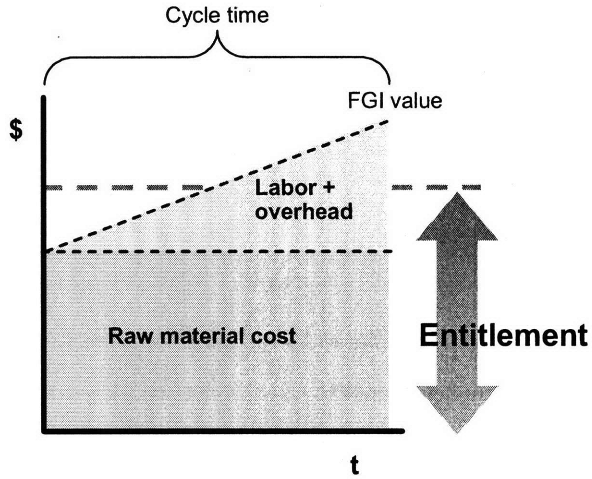


Figure 12: Work in Process (WIP) Entitlement Level

2.2.4.2.3. Finished Goods (FGI)

Finished goods inventory are part numbers that are ready to ship to customers. The entitlement is calculated on a monthly basis and is a function of future demand and stocking levels for each part as illustrated in Figure 13. FGI is entitled for sites that intentionally stock finished goods inventory, and is not entitled for sites that operate according to a make-to-order strategy.

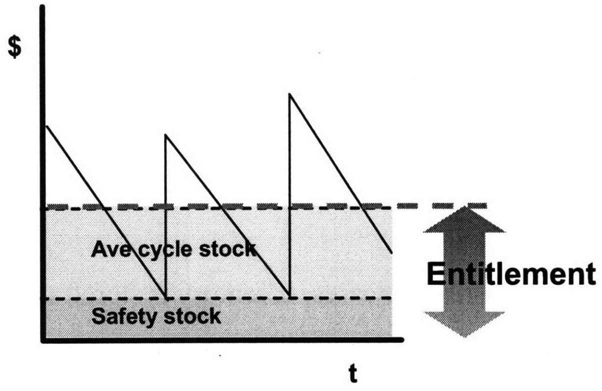


Figure 13: Finished Goods Inventory (FGI) Entitlement Level

2.2.4.3. Business Inventory

Business inventory is defined as additional stock held to support both internal and external business agreements that would not appear in usual production inventory. This inventory is in place to support multiple stakeholders, e.g. additional inventory that a sales team wants held to ensure that a key customer receives a 100% service level rather than the usual service level.

The ownership for business inventory is shared between operations and other functions, however, this inventory may reside under the operations cost structure. Operations cannot affect these stocking levels without the consent of other stakeholders.

Business inventory is further classified into twelve sub-categories with the intent of explicitly identifying shared owners. While the inventory entitlement model was created with twelve categories, this does not preclude the addition of new and different categories based on the use of a thirteenth category, “other”.

The purpose of the business inventory categories is to make these stocks visible. Once they are visible, upper management can action these stocks. The twelve categories are defined below.

1. **Anticipatory Inventory** - Stock held to address periodic large orders, which is a result of mismatches between capacity and demand. For example, if a customer requires 60 units

every two weeks, but daily production capacity is 10 units, the site will need to build stock, and hold it, in anticipation of the demand.

2. **Customer Consigned** - Stock that is held at customer sites and does not transfer to the customer's accounts until an event passes, such as a sale to an end user, or a given period or time.
3. **Customer Contractual** - In some cases, inventory is stored specifically for a customer due to contractual terms between the supplier and the customer. This inventory may be within the supplier's warehouse, a supplier hub at the customer's factory or in-transit.
4. **Deferred Revenue** - Stock, in some cases, does not transfer off a supplier's books until a contractual time period has passed.
5. **E&O** – Stock due to excess and obsolete material.
6. **Engineering** - Inventory held by a site to support engineering activities such as qualifications, process improvement initiatives, or other similar activities.
7. **LTB** - Lifetime buys are bulk purchases that take place for parts that are going end-of-life – the supplier is discontinuing production and thus the parts cannot be sourced in the future. In these cases, the site will hold inventory to support the planned lifetime, i.e. all future demand of the dependent finished good.
8. **NPI** - Inventory for new product introductions.
9. **R&O** - Inventory held to support repair and overhaul (R&O) that is in addition to site operating inventory. This inventory could be due to products that are undergoing repair or overhaul or it could be procured parts kept strictly to support R&O activity. This applies to sites with embedded R&O.
10. **SAP** – Stock, temporarily stored, to support transition from legacy ERP system to SAP ERP.
11. **Supplier Consigned** - Raw material that is procured on behalf of a supplier, e.g. when a supplier is operating with little excess working capital, or WIP that is undergoing transformation into finished goods inventory (FGI) at a supplier.
12. **TMIs** - Stock needed to support transitions, migrations or integrations, i.e. changes to procurement or transformation strategy among buyers and integrators.

2.2.4.3.1. Formulation

The formulation for each business inventory category is straightforward. The difficulty lies in accessing the data from accounting and planning systems. The entitlement is calculated on a monthly basis, using the following set of equations:

EndingBalance[n] = BeginningBalance[n] + Additions[n] + Deductions[n]

BeginningBalance[n+1] = EndingBalance[n]

Where:

n = month number

BeginningBalance[n] = business inventory stock at the beginning of month n

Additions[n] = additions to business inventory stock during month n

Deductions[n] = deductions to business inventory stock during month n, entered as a negative number

EndingBalance[n] = business inventory stock at the end of month n

Business Inventory Category	**Month[1]**	**Month[2]**	**Month[3]**	**...**	**Month[n]**
Beginning Balance	$ 100	$ 125	$ 150	$ 175	$ 200
Additions	$ 15	$ 15	$ 15	$ 15	$ 15
(Deductions)	$ 10	$ 10	$ 10	$ 10	$ 10
Ending Balance	$ 125	$ 150	$ 175	$ 200	$ 225

Figure 14: Business Inventory Formulation Example

2.3. Phase II: Rightsizing

Broadly speaking, phase II maturity means that a site or product center should know what its inventory level should be if it buffers against the appropriate sources of uncertainty. In other words, phase II maturity includes modeling and analytical approaches. Rightsizing, as phase II is known, is the second stage of a three stage maturity model that began with foundational maturity and culminates with maturity described as optimal.

Rightsizing applies math to the planning and inventory process. An inventory planning and execution tool provides a framework for manufacturing strategy (pull, make-to-order or make-to-stock) so that manufacturing strategy is a deliberate decision for each part. Different sources of variability are introduced and quantified. This is all accomplished through a seven step process that guides the setting of safety stock levels to align with pertinent sources of uncertainty.

Rightsizing advocates the use of analytically determined safety stock to buffer against sources of uncertainty, as opposed to phase I where safety stock levels were likely not based on analysis. Our intent, in phase II, is to explicitly plan for supply chain disruptions. At the same time, we intend to expose the hidden factory, e.g. where demand is positively biased, demand is fabricated, and safety stock is implicitly planned. We try to address uncertainties in a proactive manner versus the previously reactive manner.

2.3.1. People

Phase II people maturity builds on the foundation set in phase I. People apply a mathematical approach for setting planning parameters. Individuals understand when to apply different planning strategies (pull, make-to-stock and make-to-order).

2.3.2. Process

For phase II process maturity, a site should be setting system planning parameters based on supply, demand and forecast variability. The push/pull boundary, as defined in section 1.4.1.1.1, should be clearly established so that any decoupling points can be taken into consideration. The process to manage planning parameters should be done on an exception basis. Finally, value as seen by the customer becomes the focus of the system planning process.

2.3.3. Technology

In terms of tools, phase II maturity states that a standard system or tools should be deployed at the part planner level to support an exception-based review process. A multiple step, comprehensive process should also be in place to guide the rightsizing process.

2.3.4. Seven Step Rightsizing Process

The seven step rightsizing process leads to safety stock levels that buffer a product from common-cause sources of uncertainty. This safety stock level is based off of statistical methods, and serves to support the second phase of maturity.

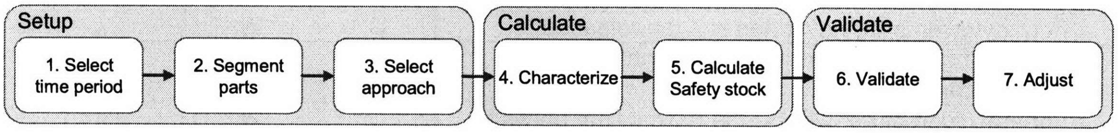


Figure 15: Seven Step Rightsizing Process

2.3.4.1. Objective

The objective of the seven step rightsizing process is to reduce the complexity (statistical analysis, academic research, etc.) involved in safety stock calculations so that users are comfortable setting safety stock levels. The seven step process applies single echelon safety stock calculations to a multi-echelon environment. It does this by considering upstream and downstream sources of uncertainty, and calculating safety stock at a single node in the supply chain.

2.3.4.2. Step 1: Select Time Period

The first step is to select an analysis time period for data collection and calculation. It is important that the time period not be chosen with the intent of influencing calculations, but rather the time period should be chosen to reflect the pulse of the organization and not introduce bias into the calculations. For example, some organizations operate on a quarterly system whereby the three months are broken into two four-week months and one five-week month. In this scenario, monthly-based calculations would need to be un-biased when reviewing the 5-week month.

The questions listed in Table 2 serve as a guide to selecting the appropriate analysis time period. The possible time period options are: day, week and month.

No.	Question	Daily	Weekly	Monthly
1.	When do order firming activities occur?	D	W	M
2.	What schedule do the planners and buyers operate to?	D	W	M
3.	How frequently is the shop planning schedule created?	D	W	M
4.	For any given part, how often is a job released?	D	W	M
5.	What is the typical order policy for high value, e.g. class A, parts?	D	W	M
6.	For any given parts, what is the typical time between orders or order frequency?	D	W	M
7.	What is the early ship window to customers, if one is in place? Circle "D" if there is no early ship window. Circle "W" it is 5 days or less. Circle "M" if it is 20 days or less.	D	W	M

Table 2: Time Period Worksheet

2.3.4.3. *Step 2: Segment Parts*

The second step of the process involves analyzing consumption uncertainty to segment parts by the planning and execution strategy. The two possible strategies are push and pull. Parts are segmented into the two strategies by considering consumption variability, while the interface between the two strategies, the push-pull boundary, is established by considering the exposure period.

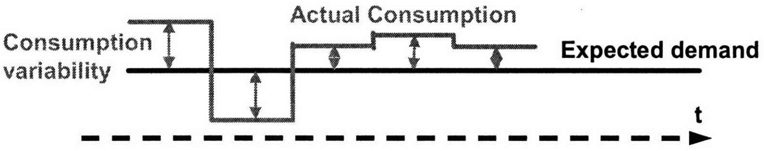


Figure 16: Consumption Variability Illustration

Consumption variability is used to determine whether a push or pull strategy will be employed. Consumption variability is sometimes referred to as demand variability. The more variation there is in demand, the higher the consumption variability will be. However, if consumption is stable, then consumption variability would be low. Figure 16 shows an example of consumption variability where actual consumption varies from the mean or expected demand.

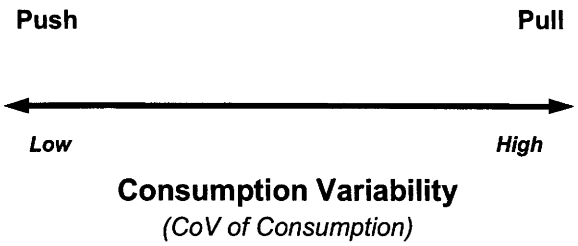


Figure 17: Inventory Planning and Execution Strategies Framework

A pull strategy should be utilized when consumption variability is high. In these instances the expected consumption is uncertain and so production should be planned based on true customer demand. On the other hand, when consumption variability is low, a push strategy can be employed. Since the expected demand is more certain, then production can be planned to forecasts.

Although the framework in Figure 17 recommends a planning and execution strategy, there are times when a site already employs a different strategy. Therefore calculations conducted in the following steps should follow the strategy (push or pull) actually employed at a site. The planning and execution strategy framework is useful when discussing how a site should be operating since it lays out, in simple terms, what the key planning and safety stock drivers are for each scenario.

The exposure period is defined as the difference between the cumulative lead-time and the customer service time. The cumulative lead-time is the amount of time it takes to procure parts and transform them into finished goods. The customer service time is the lead-time quoted to customers for delivery of product. When the cumulative lead-time is greater than the customer service time, the exposure period is positive and there is a need to carry stock in order to fulfill customer orders within the customer service time. This stock is held in a supply chain echelon that supports the customer service time. An illustration of positive exposure is shown in Figure 18.

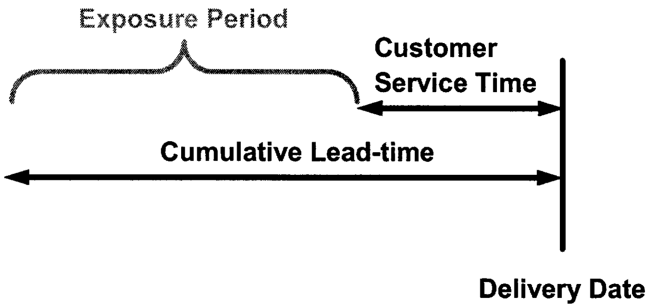


Figure 18: Positive Exposure Period Illustration – Need to Hold Stock

On the other hand, when the cumulative lead-time is less than the customer service time, the exposure period is negative and there is no need for the factory to carry stock. In these cases the factory can order parts and transform them into finished goods within the time quoted to fulfill the customer order.

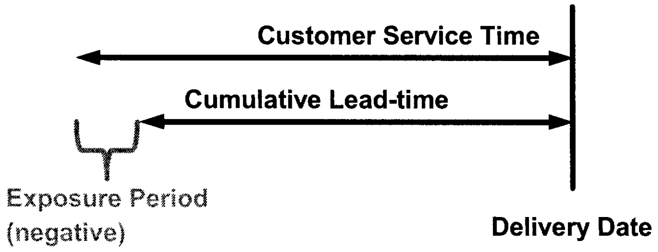


Figure 19: Negative Exposure Period Illustration – No Need to Hold Stock

2.3.4.4. Step 3: Select Approach

The third step is to identify the pertinent source(s) of uncertainty, and calculate the variability. Safety stock calculations need to be aligned with the sources of uncertainty that are pertinent to the implemented planning and execution strategy. In the case of demand uncertainty either consumption or demand may be relevant. The source selected for calculations should be the one which has less error.

The different sources of uncertainty are captured in Figure 20. Note that there is uncertainty from both upstream (referred to as supply uncertainty) and downstream (referred to as demand uncertainty). Demand uncertainty can come from two sources: consumption or forecasting.

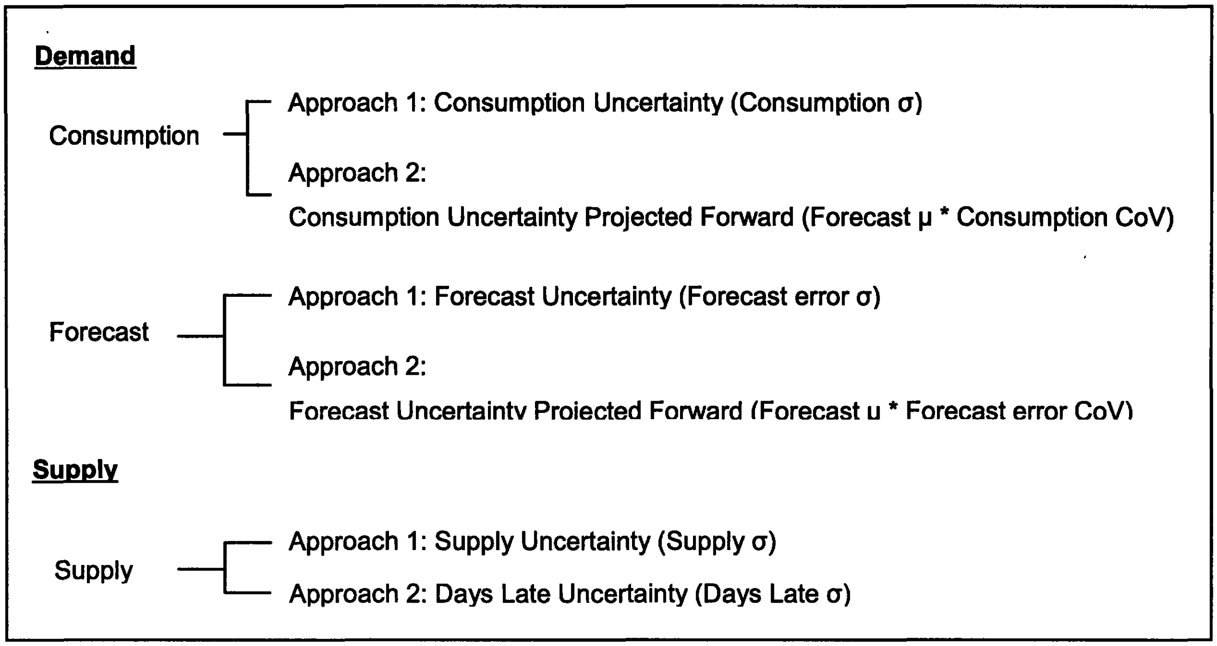


Figure 20: Variability from Demand and Supply Sources

One approach, noted in Figure 20 as Approach 1: Consumption Uncertainty and Approach 1: Forecast Uncertainty, is to simply use the past σ to calculate the variability. While a second approach, noted in Figure 20 as Approach 2: Consumption Uncertainty and Approach 2: Forecast Uncertainty, is to project the coefficient of variation forward. The general approach for this second approach is to use coefficients of variation rather than historical standard deviations, σ. For example suppose the past mean is 10 but the future forecasted mean is 5. There is reason to believe that the future variation might go down on the theory the coefficient of variation might stay stable.

2.3.4.4.1. Demand Variability – Consumption Uncertainty

Consumption is always calculated rearward looking. That is, consumption variability is calculated using past data. The question then becomes: whether to use this rearward looking variability or project the variability forward by using the coefficient of variation method.

Approach 1: Consumption Uncertainty

Approach one is to simply use past σ. Because consumption variability is calculated on past consumption data (samples of the formulas are given in Step 4.), and projected demand has the same mean as past demand, then there is no need to consider approach 2. However, when projected demand has a mean that is statistically significantly different, then consumption uncertainty should be projected forward using the coefficient of variation method, discussed in approach 2.

Approach 2: Consumption Uncertainty Projected Forward

When the mean of the master population is statistically significantly different on a forward looking basis as it has been on a rearward looking basis, then consumption uncertainty needs to be projected forward using a coefficient of variation. A coefficient of variation, sometimes represented as CoV or ρ, is a measure of dispersion of a probability distribution. It is often used when the mean of a population changes significantly from one time period to the next and is based on the belief that the coefficient of variation may stay stable. Examples of applying consumption uncertainty forward are detailed in Step 4.

2.3.4.4.2. Demand Variability – Forecast Uncertainty

A forecast is sometimes used to schedule production. In these cases, forecasts represent the uncertainty that needs to be managed and thus forecast uncertainty should be used for safety stock calculations.

Approach 1: Forecast Uncertainty

Forecast uncertainty is calculated from forecast error (examples of the calculations are discussed in Step 4). Most products that are forecasted will have a mean of projected demand that is statistically significantly different from past demand, so the forecast uncertainty will need to be projected forward using a coefficient of variation.

Approach 2: Forecast Uncertainty Projected Forward

When the mean of the master population is statistically significantly different on a forward looking basis, as it has been on a rearward looking basis, then the forecast uncertainty needs to be projected forward using a coefficient of variation (examples of applying forecast uncertainty forward are detailed in Step 4).

2.3.4.4.3. Supply Uncertainty

Regardless of the manufacturing environment, purchased goods are subject to supply uncertainty. For buy parts, this uncertainty may look like late arrivals, quality problems or quantity problems (for example, less units than were ordered). In all cases, the production schedule will be impacted. On the other hand, for make parts, supply uncertainty can take the form of any buy part supply issue (such as the three discussed above), a production quality or quantity issue, a production delay, or any other issue that causes a result different from what was expected. In order to buffer against this uncertainty, the supply variability needs to be quantified using one of two approaches.

Approach 1: Supply Uncertainty

Supply uncertainty is calculated based on rearward looking receipt data. This approach looks at early and late shipments to quantify the uncertainty (an example is given in Step 4).

Approach 2: Days Late Uncertainty

Days late uncertainty is an alternative approach to quantifying supply uncertainty. This approach does not penalize a supplier for shipments that arrive early. The standard deviation is calculated only from late shipments.

2.3.4.5. Step 4: Characterize

The fourth step is to calculate the mean and standard deviation for the demand and supply portions of the supply chain. In step 3, the different sources of uncertainty were reviewed: those that are important given the manufacturing strategy were identified and methods to quantify each were discussed. Specific examples of calculations are shown below.

2.3.4.5.1. Demand Characterization

Method 1: Consumption Standard Deviation (σ)

The consumption σ can be used to characterize parts built to a steady rate. It is the historical standard deviation from the expected consumption (consumption μ). For most situations, it is worthwhile to look back 12 months, or as long as data is available.

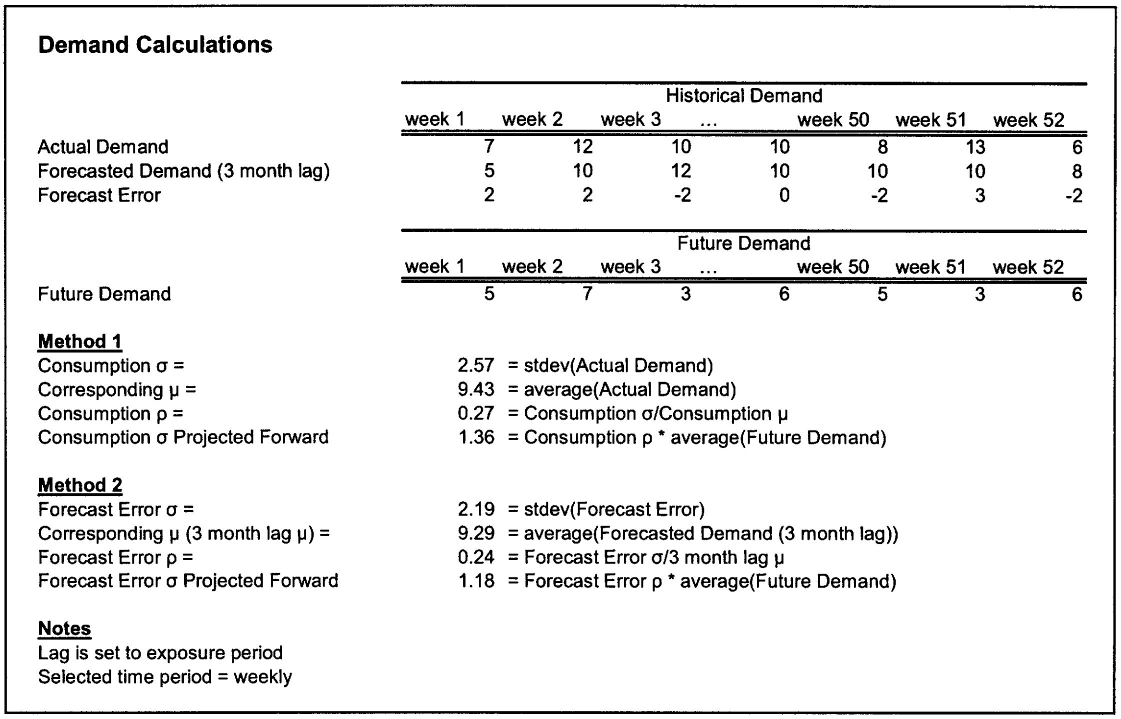
The consumption μ should be the average demand for the selected time period. For example, if the selected time period is 'week', then the consumption μ should be the average weekly demand. Example calculations of consumption standard deviation and consumption standard deviation projected forward are shown in Figure 21 under method 1.

When looking at consumption variability, it is important to monitor the coefficient of variation to check that it does not exceed 1. At CoVs of 1, the standard safety stock calculations break down because the normal distribution breaks down since it assumes a significant mass of negative values. In these cases, it is essential to look at how product is being consumed to determine what is driving the demand spikes. Typically, there will be a mismatch between the frequency at which demand is placed (monthly), and the time period of the calculation (weekly). Other causes are due to the large amount of uncertainty during a product ramp-up, i.e. new product introduction, or product ramp-down, i.e. end of life. Regardless of the cause, these cases require additional investigation and can lead to the use of judgment to set safety stock levels.

Method 2: Forecast Error Standard Deviation (σ)

We recommend using the forecast error σ when a forecast is used. In this case, the historical forecast becomes the baseline (the μ). We recommend using twelve months of data if it is available, but often this ideal was not realized. Example calculations of consumption standard deviation and consumption standard deviation projected forward are shown in Figure 21 under method 2.

As was the case when looking at consumption, we need to be careful when forecast error calculations result in a coefficient of variation that is greater than 1. We need to look at the data to determine what is causing the high variability. The causes can be similar to those cited earlier: product ramp-up, product ramp-down, demand being placed less frequently than the planning cycle and sales campaigns, but there can be many other reasons.



Demand Calculations

	Historical Demand						
	week 1	week 2	week 3	...	week 50	week 51	week 52
Actual Demand	7	12	10	10	8	13	6
Forecasted Demand (3 month lag)	5	10	12	10	10	10	8
Forecast Error	2	2	-2	0	-2	3	-2

	Future Demand						
	week 1	week 2	week 3	...	week 50	week 51	week 52
Future Demand	5	7	3	6	5	3	6

Method 1

Consumption σ =	2.57	= stdev(Actual Demand)
Corresponding μ =	9.43	= average(Actual Demand)
Consumption ρ =	0.27	= Consumption σ/Consumption μ
Consumption σ Projected Forward	1.36	= Consumption ρ * average(Future Demand)

Method 2

Forecast Error σ =	2.19	= stdev(Forecast Error)
Corresponding μ (3 month lag μ) =	9.29	= average(Forecasted Demand (3 month lag))
Forecast Error ρ =	0.24	= Forecast Error σ/3 month lag μ
Forecast Error σ Projected Forward	1.18	= Forecast Error ρ * average(Future Demand)

Notes

Lag is set to exposure period

Selected time period = weekly

Figure 21: Example Demand Calculations with formulae

2.3.4.5.2. Supply Characterization

Supply variability is caused by discrepancies in quality, receipt date or quantity. Depending on the analysis the term supply characterization can be applied to upstream suppliers, in the case of purchased parts, or a manufacturing process, in the case of transformation of purchased parts into finished goods. The point of reference is based on the analyzed echelon of the supply chain. For example, an analysis of safety stocks for finished goods, would require characterization of the variability of the preceding process: either a manufacturing process or a supply process if the finished good are purchased.

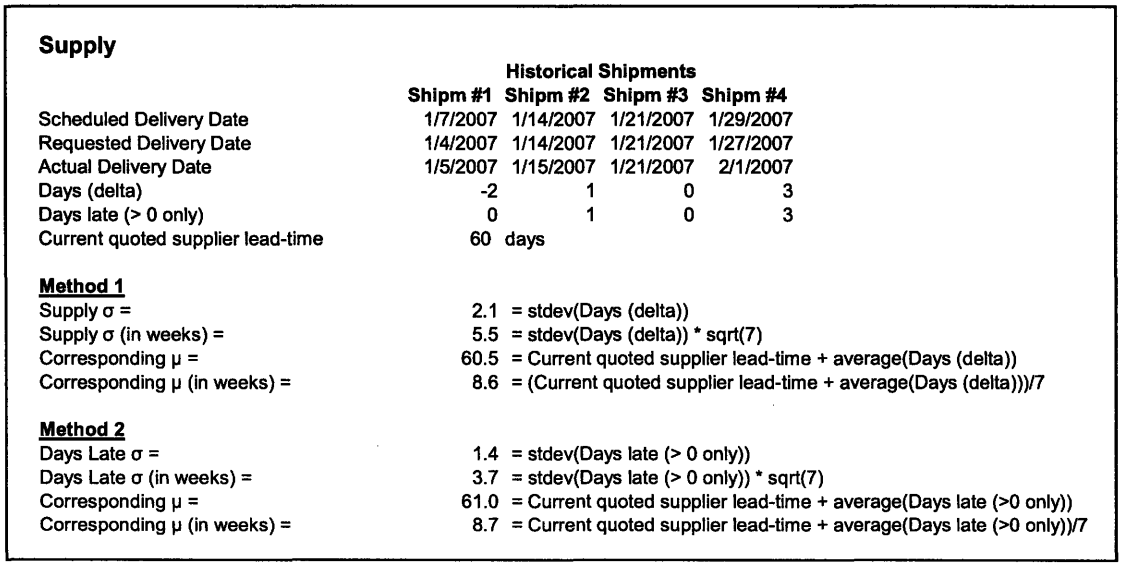
There are two methods for characterizing supply variability. The difference between the two is whether early receipts (instances where actual lead time performance is less than expected lead time), e.g. suppliers that ship material early, are included or ignored. The second method, where variability is only calculated on late arrivals means that safety stock size is not impacted by early arrivals.

Method 1: Supply σ

Supply variability, σ, is typically calculated based on the variation between scheduled and actual delivery dates. This method includes both negative and positive variance from the scheduled delivery date and thus may lead to larger safety stocks than necessary. An example of calculating the variability using this method is shown in Figure 22 under Method 1.

Method 2: Days Late σ

Days late variability is calculated on the variation between scheduled and actual delivery dates only when the difference is positive, i.e. the delivery is late. In instances where the delivery was early, the variance is taken to be zero. An example using the days late σ method is shown in Figure 22 under Method 2. Notice that for the same delivery data, the days late σ, 3.7, is less than the supply σ, 5.5. The days late approach only uses a truncated normal distribution as opposed to a regular 2-sided distribution and hence will have a lower σ. A larger z value may be advisable in this situation.



Supply

	Historical Shipments			
	Shipm #1	**Shipm #2**	**Shipm #3**	**Shipm #4**
Scheduled Delivery Date	1/7/2007	1/14/2007	1/21/2007	1/29/2007
Requested Delivery Date	1/4/2007	1/14/2007	1/21/2007	1/27/2007
Actual Delivery Date	1/5/2007	1/15/2007	1/21/2007	2/1/2007
Days (delta)	-2	1	0	3
Days late (> 0 only)	0	1	0	3
Current quoted supplier lead-time	60	days		

Method 1		
Supply σ =	2.1	= stdev(Days (delta))
Supply σ (in weeks) =	5.5	= stdev(Days (delta)) * sqrt(7)
Corresponding μ =	60.5	= Current quoted supplier lead-time + average(Days (delta))
Corresponding μ (in weeks) =	8.6	= (Current quoted supplier lead-time + average(Days (delta)))/7
Method 2		
Days Late σ =	1.4	= stdev(Days late (> 0 only))
Days Late σ (in weeks) =	3.7	= stdev(Days late (> 0 only)) * sqrt(7)
Corresponding μ =	61.0	= Current quoted supplier lead-time + average(Days late (>0 only))
Corresponding μ (in weeks) =	8.7	= Current quoted supplier lead-time + average(Days late (>0 only))/7

Figure 22: Example Supply Calculations with formulae

2.3.4.5.3. Demand and Supply Variability

In cases where both demand and supply variability is a factor, the equation in Figure 23 should be utilized. This combines both sources of variability into a common standard deviation.

$$\sigma = \sqrt{E(L) * \mathrm{var}(D) + [E(D)]^2 * \mathrm{var}(L)}$$

Where:

E(L) = Expected (average) lead-time
var(L) = Lead-time variance
E(D) = Expected (average) demand
var(D) = Demand variance

Figure 23: Combining Variability from Supply and Demand Sources

2.3.4.6. Step 5: Calculate Safety Stock

The fifth step is to calculate the safety stock using the variability found in step four and the appropriate service level. Type I service level will be used because it is more conservative. Type I service level is event-oriented and is based on the probability that there will be no stock out. Type II service level, on the other hand, is based on the fill rate and is quantity-oriented. For type I service level, Table 3 gives the corresponding safety factor, z.

Service Level	Safety Factor (z)**
80%	0.84
85%	1.04
90%	1.28
95%	1.64
97%	1.88
98%	2.05
99%	2.33

**=normsinv(Service Level)

Table 3: Service Level with Corresponding Safety Factor

The safety stock should be calculated on a part by part basis using the formula shown in Figure 24. Once calculated the safety stock levels need to be analyzed, as will be discussed in step 6, and the aggregate safety stock level may need to be reviewed in the context of other business priorities.

$$SS = z\sigma\sqrt{[r+L]}$$

Where:

SS = safety stock level
z = Service factor
L = Lead-time
r = Review period, if applicable
σ = Standard deviation

Figure 24: Safety Stock Formula

In some cases an inventory-by-cause analysis is recommended to determine what the different drivers of safety stock are. This analysis looks at the result of supply variability, demand variability, lead-time and review period to assess which source(s) are primarily responsible for the safety stock. This allows an organization to decide between some combination of addressing the safety stock drivers and positioning safety stock.

2.3.4.7. Step 6: Validate

The sixth step is to validate the safety stock levels calculated in step five. Normally this involves an analysis of the levels, in terms of value and quantity, to identify any abnormally large levels. Quantity can be reviewed in terms of numbers of units or preferably days of supply, DOS, or months of supply, MOS. Then a root cause analysis should be undertaken to determine whether the causes of the abnormally large levels are likely to repeat (common cause) or extraordinary events (special cause).

2.3.4.7.1. Special vs. Common Cause Analysis

Once safety stocks are calculated, validation of safety stock causes is necessary in order to reduce over-buffering. First, outlier parts must be identified. Outliers are parts that have excessive safety stock, in terms of units and/or value, when compared with the bulk of parts. Figure 25 provides an example of an outlier analysis.

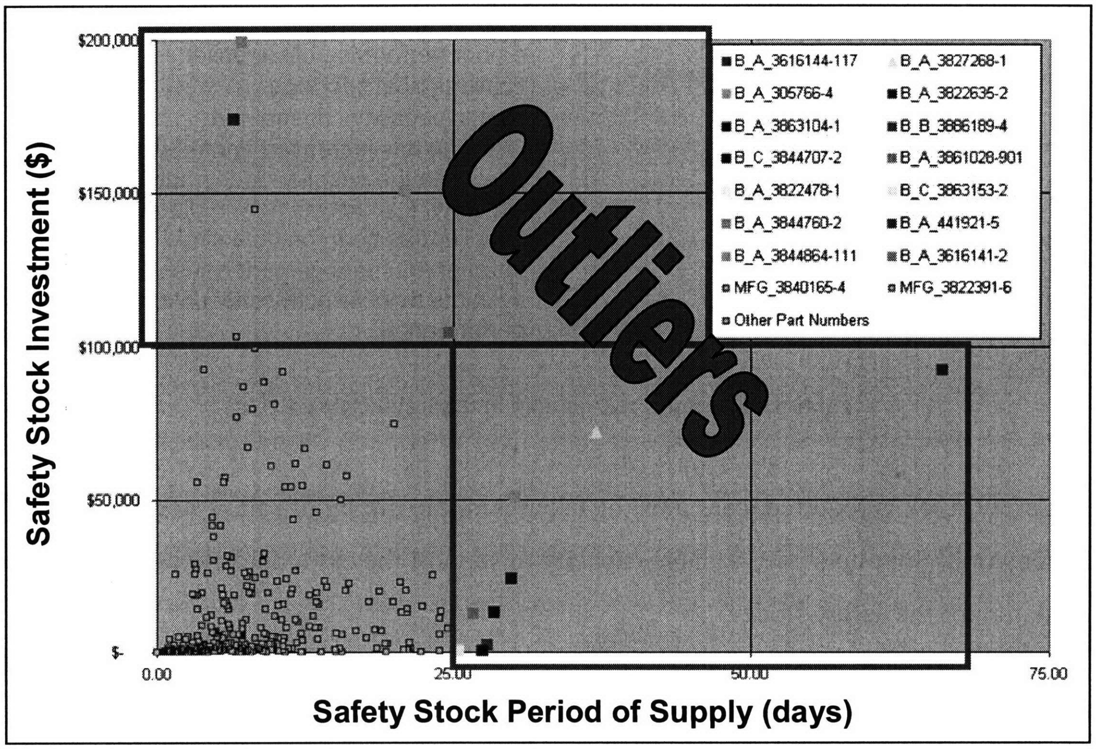


Figure 25: Safety Stock Levels (in $ and days) with Outliers Highlighted

Next, for all outlier parts an analysis should be done to determine whether the safety stock drivers are common or special cause. Safety stock should only be used to cope with common cause drivers, while an adjustment to the safety stock levels will be needed for special cause drivers. While this analysis is somewhat subjective, the table below should serve as a guide to support the process.

Common Cause	**Special Cause**
• Consistent yield problems.	• Failed transition to a new supplier. (Evaluate safety stock need based on history for current supplier only.)
• Consistent material availability issues.	• Supply chain disruption has been remedied as of a certain date, and supplier is delivering consistent quality shipments since that date.
• Repeat quality issues.	• Supplier is late due to organization-driven pull-ins. (In this case the organization is driving the variability in receipts.)
• Consistent late deliveries.	• Part had past history of late receipts, but those issues have been resolved.

	• Successful transition to new supplier from a poor performing old supplier. • Raw material shortage • Part is capacity constrained • Demand has increased and receipts were late while the supplier added additional capacity. Capacity is now in place and supplier has been on time since. • Internal PO management issues cause systems to incorrectly reflect poor delivery performance.

Table 4: Examples of Common and Special Cause Events

Where safety stock is required, care must be taken with the timing of safety stock implementation. Suppliers need to have capacity to support the extra demand caused by the accumulation of the safety stock.

2.3.4.7.2. Coefficient of Variation Analysis

Validation is also an important step for any parts where the coefficient of variation, CoV or ρ, used in calculations is close to 1 or higher. In these cases, the standard set of safety stock calculations begin to breakdown because the underlying assumption of normality of the distribution of data breaks down. Again because the normal distribution will have significant negative mass. In order to assess the calculated safety stock level it is important to take a closer look at the underlying data.

Typically, a closer look at the data will show intermittent consumption (if consumption is the safety stock driver), poor forecast accuracy, positive or negative forecast bias, or some other unusual pattern with the data. In these cases it is imperative to discuss the situation with the applicable planner, e.g. demand planner, shop floor planner.

At times, it may be best to subjectively set a safety stock level using common sense and what is known about the customers' demand situation. For example, in Figure 26, the forecast for PN 4059021-903 has positive bias, but also very low consumption, 7 units in 39 weeks. In this example, the forecast error CoV was close to 2 and the safety stock recommendation was disproportionately large.

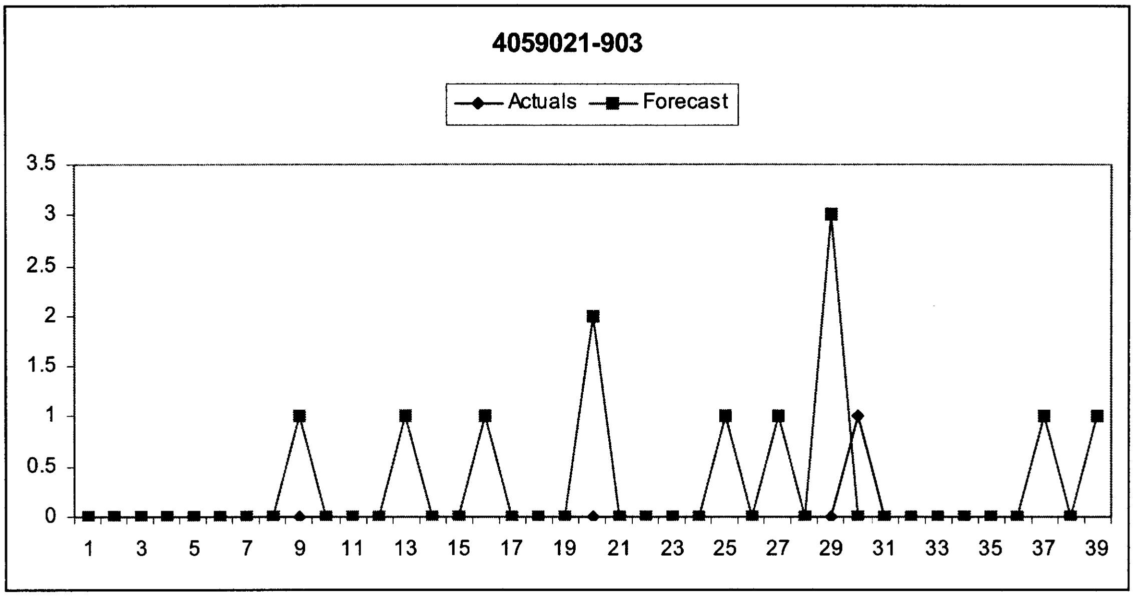


Figure 26: Forecast vs. Actual Consumption Comparison for Example Part (Note some actual data points are hidden behind forecast data points)

So, for this example, there is a need to understand the story behind the data. Maybe this is a new part. Maybe it's a highly profitable part with a short customer service time – so profitable that the demand team is happy to overdrive demand. In this scenario, a couple conversations are certainly warranted. In the end, if this situation cannot be improved, it may be best to subjectively set a safety stock, and thus not use the normal distribution, by looking at the cumulative distribution of the forecast and setting a service level to cover 95% of the demand. Depending on the manufacturing lead-time, we could see how that would give a safety stock of 1 unit, which would cover all actual demand.

2.3.4.7.3. High Profit Margin Product

In cases where the product being analyzed has an exceptionally high profit margin it is important to factor in the associated revenues and profits, and not simply look at cost (inventory). In these cases a marginal analysis can be conducted to help estimate how much safety stock to consider. Inventory textbooks call a simplified version of this approach, in which the amount that can be sold is unknown, but the revenues and costs can be quantified, the newsvendor model. By looking at the cost of overage and cost of underage we can determine how many units to stock.

2.3.4.8. Step 7: Adjust

The seventh and final step involves adjusting the data to remove special cause factors and repeating steps four and five. If no adjustment, from step six, is necessary, then step seven should trigger an update of the safety stock levels into planning systems.

2.4. Phase III: Optimization

Phase III of the inventory management maturity model is concerned with inventory levels across the entire supply chain. Planning parameters are based on multi-echelon analysis, and planning parameters are coordinated across the supply chain. The focus on the entire supply chain is what makes phase III so dramatically different from phase II. In phase II we were concerned with a single echelon of the supply chain, a single place where safety stock could be positioned. But now in phase III there are opportunities to optimize safety stock at multiple positions within the supply chain, for example, by significantly reducing or eliminating safety stock at multiple locations.

Phase III also requires that dedicated personnel be used to conduct intensive quantitative analysis using multi-echelon inventory analysis and network optimization tools. While activities comprising phase III maturity were not covered in the author's internship the tools necessary to reach phase III maturity are in place at Honeywell Aerospace and have been successfully deployed in past projects. For an example application of multi-echelon inventory analysis, please see Lo (2007).

2.4.1. People

At phase III maturity people in the organization demonstrate an understanding of inventory deployment strategy across the supply chain. Individuals understand concepts and the benefits of decoupling, postponement and risk pooling. Most importantly, the need for a specialized role, such as a supply chain engineer or architect, would be required to focus on the intense analysis required.

2.4.2. Process

From a process perspective, phase III maturity means that system planning parameters are based on global optimization, e.g. multi-echelon. Processes also support coordination of planning policies across the supply chain to deliberately set decoupling points, make use of postponement strategies, pool inventory and take advantage of nesting opportunities.

2.4.3. Technology

The technology frame for phase III requires that a toolset be available for supply chain engineers so that they can conduct deep quantitative analysis. This toolset may consist of multi-echelon inventory optimization and logistics network optimization software. Honeywell Aerospace owns licenses for Optiant PowerChain, a multi-echelon inventory optimization software package. Optiant has been successfully been applied at Honeywell. For further reference, we recommend Lo (2007) where Optiant was applied to two product families within Honeywell Aerospace.

This page has been intentionally left blank

3. Part III: Application of the Inventory Management Maturity Model to Honeywell Aerospace

This chapter walks through two applications of the Inventory Management Maturity Model. First, the Inventory Entitlement Model was applied to one of the factories in the Engines Product Center as a proof of concept for the model. Then, the 7 Step Rightsizing Process was applied to a product family in the Avionics Product Center. For each application, there is a discussion of the model setup, including assumptions, and the results, in the context of the model and the business.

3.1. Phase I: Foundational

For the proof of concept for the Inventory Entitlement Model, two manufacturing sites were chosen. This example is the implementation at the Engines Product Center in Phoenix. Phoenix Engines, as it is commonly called is the largest single site by value and thus, in theory, would present some unique challenges when setting up the model. The purpose of applying the Inventory Entitlement Model at Phoenix Engines was also to gain some insight into what variances may exist between actual inventory performance and calculated entitlement.

3.1.1. Engines Product Center (EPC)

Honeywell Aerospace's Engines Product Center (EPC) main facility is located in Phoenix, AZ. The EPC builds, assembles and tests engines for commercial and military use. This product center's products can be subdivided into three families: commercial propulsion products, commercial auxiliary power units and other auxiliary power units for military, helicopter, industry and marine.

The Phoenix manufacturing site is broken into four facilities: three centers of excellence (COEs) and one assembly and test center. The three COEs make gear line components, rotating and circular components and casing structures, while the assembly and test center integrates and tests components from the three COEs, other Honeywell facilities and external suppliers. The Phoenix EPC supply chain is shown in Figure 27.

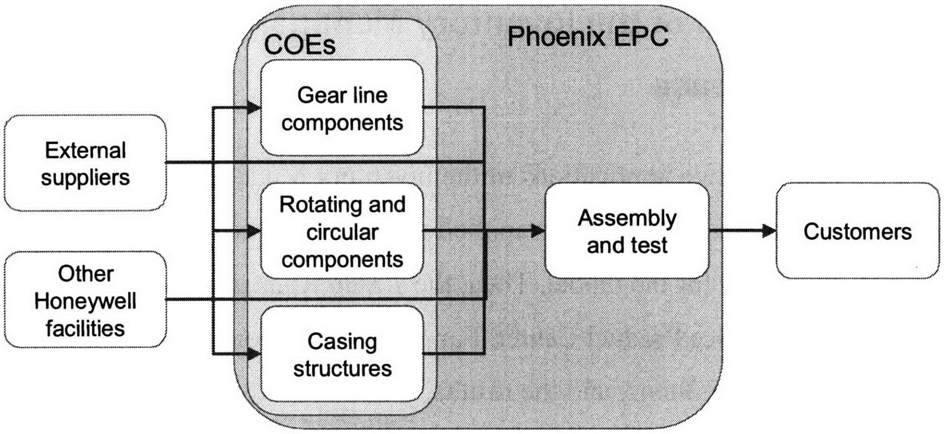


Figure 27: Phoenix Engines Product Center Supply Chain

3.1.2. Model Setup

One Inventory Entitlement Model was populated for all of the Phoenix EPC as a proof of concept. The model was populated with data pulled from their legacy MRP system MacPac and from some different accounting sources. A detailed discussion follows.

3.1.2.1. Site Operating Inventory

The Site Operating Inventory section of the Inventory Entitlement Model is summarized in Table 5. From a quick review of the categories, we can observe that Phoenix Engines buys raw material through MRP (listed under Raw), buys raw material through a supplier pull program (Raw on pull), transforms WIP into finished goods (WIP) and builds some WIP to inventory (WIP OH). The WIP OH is due to inventory that is stored between the three COEs and the one assembly and test center, as shown in Figure 27.

The total entitlement for the Site Operating Inventory section is shown to range from $125 to $130 million over the first calendar quarter of 2008. Although not explicitly compared in this text, this number is lower than the actual inventory held in these stores. This variance led to some inventory reduction projects, which will be discussed in 3.1.3 below.

		2008.01	2008.02	2008.03
Site Operating Inventory	**Raw**	$ 38,384,246	$ 37,558,683	$ 36,897,257
	Raw (on pull III)	$ 26,526,658	$ 27,539,291	$ 26,463,212
	WIP (planned)	$ 56,928,855	$ 65,297,119	$ 63,781,990
	WIP OH	$ 3,294,097	$ 3,346,567	$ 3,231,645
	Sub-Total	$ 125,133,856	$ 133,741,661	$ 130,374,104

Table 5: EPC Site Operating Inventory

3.1.2.2. Business Inventory

Business Inventory is unique to each site. Phoenix Engines, as shown in Table 6, had consigned inventory, deferred revenue, excess and obsolete material, an upcoming SAP transition, some product site transfers and raw material strategic buffer. We explore these in order. First, the consigned figures are for inventory that has been shipped to a customer, but the ownership of the inventory does not transfer until Honeywell's customer sells the product to its customer. Next, the deferred revenue charges are for inventory ownership transfers that take place after a certain period of time. Phoenix Engines cannot book these sales until a period of time has passed. Excess and Obsolete charges are for inventory that is in stock but no longer needed. This inventory can no longer be sold to customers. It is important to note that the figures entered are net of any accounting reserve. The next item listed, under SAP, is related to the inventory build ahead that is necessary before the switch from a legacy MRP system to SAP. TMI is a Honeywell term covering product site transitions. The figures listed indicate that products are being in-sourced and/or product inventories are being increased in anticipation of an out-sourcing activity. Finally, and perhaps most importantly, the final row is an entry for a raw material buffer. This strategic buffer was put in place when commodity prices started climbing a few years ago. The buffer covers raw materials that are used at multiple plants within Honeywell, yet the buffer sits exclusively on the books of Phoenix Engines.

		2008.01	2008.02	2008.03
Business Inventory	**Consigned - CCAD**	$ 3,400,000	$ 3,700,000	$ 4,000,000
	Consigned - Tiger	$ 4,500,000	$ 4,500,000	$ 4,500,000
	Deferred Revenue	$ 34,000,000	$ 34,000,000	$ 34,000,000
	E&O (net)	$ 20,000,000	$ 20,000,000	$ 20,000,000
	SAP	$ -	$ -	$ 8,000,000
	TMI	$ 4,481,000	$ 4,481,000	$ 4,481,000
	Other (General) - RM Buffer	$ 20,500,000	$ 21,500,000	$ 21,500,000
	Sub-Total	$ 86,881,000	$ 88,181,000	$ 96,481,000

Table 6: EPC Business Inventory

3.1.2.3. Inventory Entitlement Total

Table 7 combines the entitlement for site operating inventory and business inventory to give a single entitlement figure. The entitlement is also shown in terms of days of supply, which are based off of Phoenix EPC's cost of goods sold and Honeywell's formula for calculating days of supply.

		2008.01	2008.02	2008.03
Inventory Entitlement	Total	$ 212,014,856	$ 221,922,661	$ 226,855,104
	DOS	67.3	77.4	58.2

Table 7: EPC Inventory Entitlement

3.1.2.4. Assumptions & Clarifications

For the proof of concept at Phoenix Engines, there is one important assumption that was made. There is some overlap between business inventory and site operating inventory. For example, the TMI business inventory item overlaps with some raw material site operating inventory because the way the TMI build ahead is accomplished is by placing artificial demand into the system. These overlaps are difficult to separate and are left as is since the Inventory Entitlement model aims to provide a simple ballpark figure of where a site should be. In a similar vein, one can envision similar overlap between dollar value captured in the SAP business inventory category and parts in the site operating inventory category.

3.1.3. Results

Overall the implementation of the Inventory Entitlement Model with Phoenix Engines helped EPC management and Honeywell Aerospace upper management see where EPC should be from an inventory perspective. It identified opportunities to reduce variance to entitlement for raw materials, for example, while at the same time making a case for their structural inventory requirements in the business inventory section. For example, Phoenix Engines holds a strategic raw material reserve of $20 million. Part of this, in theory, benefits Phoenix EPC while most of this benefits other product centers. This strategic buffer cannot be transacted by Phoenix EPC alone. It is very difficult for Phoenix EPC, by itself, to affect the size or composition of this inventory. The second requirement brought to light in the business inventory section is the inventory held on behalf of customers, either in the form of consigned inventory or deferred revenue. Together these total $40 million on a monthly basis.

It would be short sighted to state that Phoenix Engines was simply allowed to make its case that the business inventory was difficult to action. In reality, Phoenix Engines put together specific inventory reduction projects targeted at specific business inventories. These projects included attempts to move the location of consigned inventories and resulted in pro-active efforts to influence contracts with customers that were perceived to provide overly generous inventory benefits to customers.

After the successful proof of concept with Phoenix Engines Product Center and a second proof of concept with the Tempe AALS site, the Inventory Entitlement Model was accepted by management and became a requirement, for the top 10 sites by cost of goods sold representing 80% of Honeywell Aerospace cost of goods sold, for annual operating planning (AOP). A training program was put together and all product centers were trained on the model.

As the inventory entitlement model became widely used two issues became clear. First, there was a need to understand what was behind the variances to entitlement. It became clear, quite quickly, that the variances were due to execution issues. Actually, what appeared to be execution issues on the surface were really the inability of the current inventory and planning processes to adequately identify and then buffer against uncertainty. So, an effort was started to look at aligning safety stocks with sources of uncertainty (which culminated in the second phase of the Inventory Management Maturity Model). Second, there was a pull for additional models to bring the same philosophy and same calculations to different aspects of a factory: product families, inventory planners and factories within a factory. These additional models became known as extensions, and will be discussed in the next section.

3.1.3.1. Model Extensions

The first three model extensions were applications of the Inventory Entitlement Model to different areas of or individuals in a factory. These were:

1. Product families
2. Inventory planners
3. Centers of Excellence

The product family analysis reviewed all buy parts associated with a family of end products. The model helped to focus inventory reduction efforts on where the biggest opportunities were. For example, the analysis run on the T55 project, at Phoenix EPC, pointed to poor execution of the supplier pull project as an opportunity to reduce inventory levels. The planner entitlement analysis, at Tempe AALS, was run on a monthly basis to see which inventory planners were bringing in too much material with respect to their forecasted needs. This same analysis was also being adopted by the GES product center. Finally, the Center of Excellence analysis was put in place at Phoenix EPC to calculate entitlement for each manufacturing center, called COEs, individually (see Figure 27 for a diagram of Phoenix EPC) as opposed to entitlement at the aggregate level. This model was created towards the end of my internship, but I have heard positive comments about it.

There are two other extensions that I will briefly discuss:

1. Part classification analysis
2. Order policy optimization

First, the part classification analysis was run in order to revise the order policies for purchased parts. Honeywell Aerospace typically classifies parts into A, B and C groups by past spend. The Inventory Entitlement model made this analysis quicker, since all the necessary data was contained within the model. Secondly, an initiative was started to look at changing the order policy part classification, e.g. classifying parts into A, B and C groups by past spend, to focus on all of Honeywell Aerospace instead of each individual site. In other words, a site may no longer have an A, B and C order policy but may only stock parts according to a B and C order policy if, for example, its parts had low past spend relative to parts at other sites. This initiative also used the data gathered in the Inventory Entitlement model.

3.2. Phase II: Rightsizing

3.2.1. Avionics Product Center (APC)

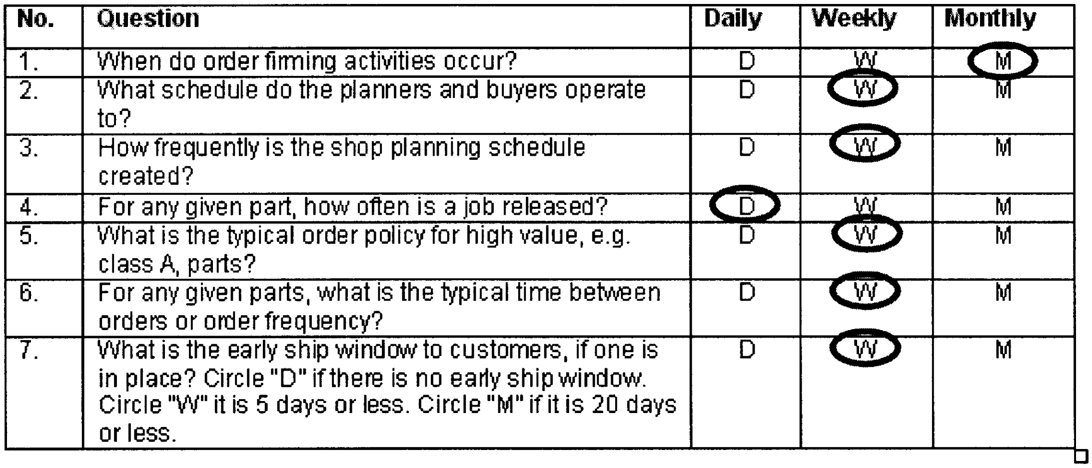
A proof of concept for the Seven Step Rightsizing Process was carried out on the top ten Air, Transport and Regional (ATR) products, by trailing 12 month revenue, built by the Avionics Product Center (APC). Avionics systems are the application of electronics to aviation and comprise all electronics systems – including communications, navigation and the display and management of multiple systems – designed for use on an aircraft, including communications, navigation and the display and management of multiple systems. At Honeywell, the APC assembles products ranging from displays and cabinets to platform and Radio Frequency sensors.

3.2.2. Model Setup

The discussion will walk through the seven steps.

3.2.2.1. Step 1: Select Time Period

The first step is to select an appropriate time period for analysis using the time period worksheet. Table 8 shows a completed time period worksheet for the ATR products at APC, where we can observe that most activities occur on a weekly basis. Thus we will go forward with a weekly time period for all calculations.



No.	Question	Daily	Weekly	Monthly
1.	When do order firming activities occur?	D	W	[✓ M]
2.	What schedule do the planners and buyers operate to?	D	[✓ W]	M
3.	How frequently is the shop planning schedule created?	D	[✓ W]	M
4.	For any given part, how often is a job released?	[✓ D]	W	M
5.	What is the typical order policy for high value, e.g. class A, parts?	D	[✓ W]	M
6.	For any given parts, what is the typical time between orders or order frequency?	D	[✓ W]	M
7.	What is the early ship window to customers, if one is in place? Circle "D" if there is no early ship window. Circle "W" it is 5 days or less. Circle "M" if it is 20 days or less.	D	[✓ W]	M

Table 8: Completed Time Period Worksheet for ATR Products at APC

3.2.2.2. Step 2: Segment Parts

In step 2, we need to segment the parts by planning and execution strategy. First we calculate the consumption variability and coefficient of variation as shown in Table 9. We can see that the consumption CoV ranges from a very reasonable 0.417 to a very high 2.166. Since consumption CoV has such a wide range, we should most likely be employing a pull strategy.

	Consumption σ	**Consumption μ**	**Consumption ρ**
4059021-903	0.389	0.179	2.166
4059027-903	0.442	0.256	1.725
7516118-27010	1.530	1.641	0.932
7516118-27140	1.513	1.641	0.922
7516250-20050	1.317	1.718	0.767
7520000-20140	1.762	2.000	0.881
7520061-34010	1.579	1.923	0.821
HG2050AC07	5.058	12.128	0.417
HG2060AD01	1.945	1.538	1.264
HG2100AB04	1.987	1.000	1.987

Table 9: Consumption Variability

Next we need to analyze the Exposure Period, to see whether we need to carry safety stock and if so where that safety stock should be held. As we can see in Table 10, the cumulative lead-time ranges from 1.5 to 9.4 months while the customer service time is typically 1 to 2 months. Since we know that transformation, within the four walls of APC, generally takes 1-2 weeks we can safely say that any safety stock should be held in raw materials.

Part Number	Cumulative Leadtime (mos.)	Customer Service Time
4059021-903	9.13	Typically 1-2 months
4059027-903	6.60	
7516118-27010	1.50	
7516118-27140	2.17	
7516250-20050	6.33	
7520000-20140	2.23	
7520061-34010	2.23	
HG2050AC07	7.17	
HG2060AD01	9.40	
HG2100AB04	7.17	

Table 10: Exposure Period

3.2.2.3. Step 3: Select Approach

APC was operating a push environment and building to a forecast. A request was made to calculate safety stock levels for finished goods, so the analysis that follows is based on forecast error. Normally we would also consider supply variability but data was not available and so it was omitted from the calculations.

3.2.2.4. Step 4: Characterize

To characterize demand variability, we looked at forecast error standard deviation. The forecast error standard deviation was calculated using a three-month lag. This is considered to be the normal exposure period for Honeywell – the period that Honeywell needs to protect against.

The results of the forecast error calculations are shown in Table 11. We can see that for some products, such as HG2050AC07 and HG2060AD01, the forecast accuracy is good. (Remember that we are looking at weekly data.) However, for other parts the CoV approaches and then exceeds 1 and thus we will have to investigate these parts further.

	Forecast Error σ	Forecasted Demand μ	Forecast Error ρ
4059021-903	0.615	0.308	1.998
4059027-903	0.223	0.308	0.726
7516118-27010	1.662	1.615	1.029
7516118-27140	2.264	2.564	0.883
7516250-20050	3.098	2.795	1.109
7520000-20140	3.343	3.333	1.003
7520061-34010	3.331	3.103	1.074
HG2050AC07	3.079	12.436	0.248
HG2060AD01	0.742	1.769	0.419
HG2100AB04	2.723	1.487	1.831

Table 11: Forecast Error σ, μ and CoV

3.2.2.5. Step 5: Calculate Safety Stock

In step 5 we calculate the safety stock using the forecast error σ. We use a 95% service level for these calculations, which gives us the safety stock levels shown in Table 12.

Part Number	Safety Stock	DOS
4059021-903	41	148
4059027-903	10	49
7516118-27010	5	31
7516118-27140	11	34
7516250-20050	37	69
7520000-20140	13	38
7520061-34010	14	41
HG2050AC07	34	16
HG2060AD01	14	32
HG2100AB04	65	119

Table 12: Safety Stock Due to Forecast Error Uncertainty

3.2.2.6. Step 6: Validate

In step 6, we have the all-important exercise of validating the safety stock levels calculated in step 5. We already know, from step 2, that consumption CoV has a wide range, and we also know that forecast error CoV, from step 4, has a wide range. Let us walk through, in much greater detail, the statistics to better understand what's driving the safety stock levels.

3.2.2.6.1. HG2050AC07

Table 13 summarizes the key statistics for part HG2050AC07. The safety stock level, of 34 units or 16.3 days of supply, looks very reasonable. The forecast accuracy, as indicated by the low Forecast Error, is very good. We can see that there is a slight up tick in the expected demand going forward, to 14.571 units/week from 12.436 units/week so we projected the Forecast Error σ forward using the CoV method.

Consumption CoV	0.417
Forecast Error σ	3.079
Forecasted Demand μ	12.436
Forecast Error CoV	0.248
Future Demand μ	14.571
Forecast Error σ Projected Forward	3.608
Lead-Time	31 Weeks
z	1.64 (95% SL)
Safety Stock Level	34 Units 16.3 DOS

Table 13: HG2050AC07 Key Statistics

From this review, we can conclude that the safety stock recommendation for part HG2050AC07 is reasonable because the conditions of normality are met (CoV < 1).

3.2.2.6.2. 4059027-903

Part 4059027-903 is for an UPS specific MD-11 upgrade. We can see that historically consumption was highly variable, as seen by the consumption CoV of 1.725 while forecasts were okay as indicated by a Forecast Error CoV of .726. What is really driving the high safety stock level of 49 days of supply is a big increase, 4.7 times, in future expected demand from past average demand. This is due to the MD-11 upgrade campaign and after speaking with the demand planner, I learned that all expected demand was entered into the system. The question remains whether this safety stock level could be reduced to save some money and still provide a high service level. If we feel that future forecast accuracy will follow past forecast performance, then it is best to leave this safety stock level as it is.

Consumption CoV	1.725
Forecast Error σ	0.223
Forecasted Demand μ	0.308
Forecast Error CoV	0.726
Future Demand μ	1.438
Forecast Error σ Projected Forward	1.044
Lead-Time	28.6 Weeks
z	1.64 (95% SL)
Safety Stock Level	10 Units 49 DOS

Table 14: 4059027-903 Key Statistics

3.2.2.6.3. 7516118-27010

Consumption CoV	0.932
Forecast Error σ	1.662
Forecasted Demand μ	1.615
Forecast Error CoV	1.029
Future Demand μ	1.125
Forecast Error σ Projected Forward	1.158
Lead-Time	6.5 Weeks
z	1.64 (95% SL)
Safety Stock Level	5 Units 31 DOS

Table 15: 7516118-27010 Key Statistics

Part 7516118-27010 has a Forecast Error CoV of 1.029. Since it is greater than 1, we should look into the historical forecast versus actual consumption. Figure 28 shows that the forecast looks decent, but there is probably a chance to do better. For example, there is a huge spike in actual consumption in week 8 that was missed. The average of the actual consumption is 1.641 while the average of the forecast 1.615 which indicates that there isn't any bias in the forecast and that overall the forecasts may have just been off by a week to cause the high Forecast Error CoV.

The demand planner said that these units are sold to Boeing and Airbus and that Boeing and Airbus provide a forecast of when they will be needed. It was unclear what caused the spike in week 8.

So, in conclusion, we recommended the safety stock level of 5 units to start. After some time this level would need to be re-visited to see how well the forecast was holding up with the hope that the safety stock level could be reduced.

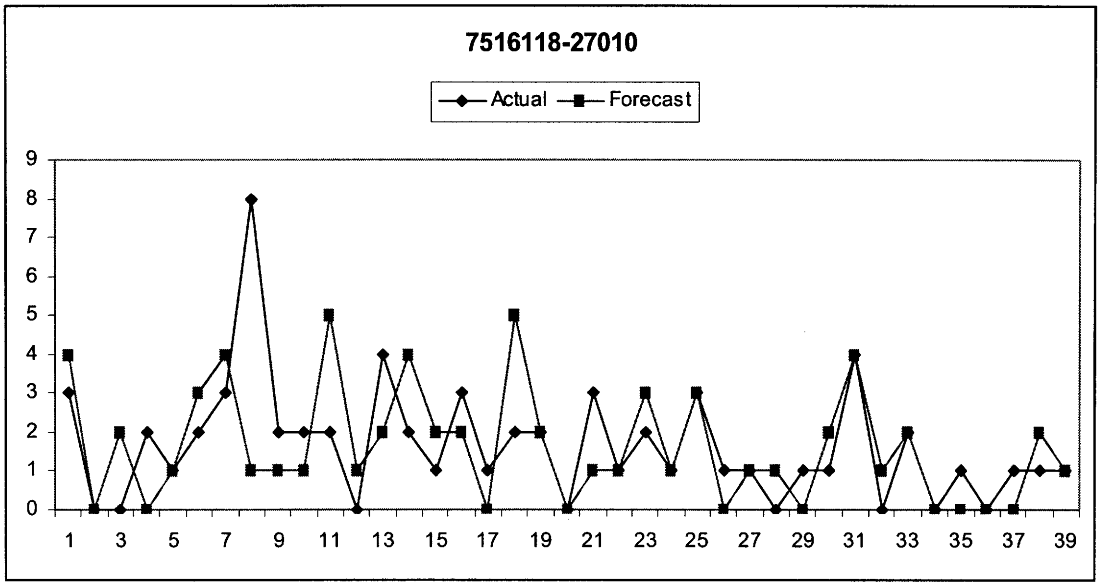


Figure 28: 7516118-27010 Actual Historical Consumption versus Forecast

3.2.2.6.4. 7516250-20050

Consumption CoV	0.767
Forecast Error σ	3.098
Forecasted Demand μ	2.795
Forecast Error CoV	1.109
Future Demand μ	3.778
Forecast Error σ Projected Forward	4.188
Lead-Time	27.4 Weeks
z	1.64 (95% SL)
Safety Stock Level	37 Units 69 DOS

Table 16: 7516250-20050 Key Statistics

Part number 7516250-20050 is another part with a Forecast Error CoV close to 1, so we should disregard the safety stock recommendation until we take a closer look at the historical consumption and forecast data. Figure 29 shows that there are a couple of huge spikes in forecasted demand relative to what was consumed. In speaking with the demand planner, these were identified as demand that has yet to materialize but has been placed in the forecast due to the long lead-time. We can see in the chart that this has led to a positive bias in the forecast. Mathematically, the Actual consumption average of 1.718 versus the forecast average of 2.795 confirms the positive forecast bias.

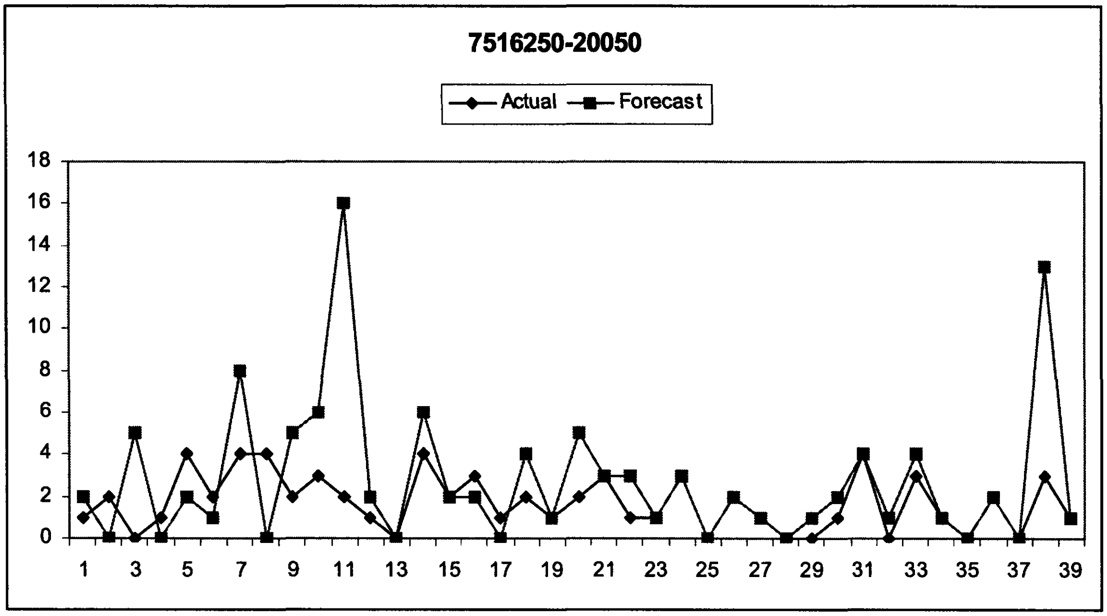


Figure 29: 7516250-20050 Actual Historical Consumption versus Forecast

These two forecast demand spikes, in weeks 11 and 38, are good examples of special cause issues that we cannot necessarily expect to plan for. This demand that has yet to materialize may never materialize and thus we cannot let it drive our safety stock levels higher than they should be.

In this case, it was recommended that the safety stock calculations be re-run with the two forecast demand spikes, removed. This results in a reduction in the safety stock level to 25 units, or 46 days of supply, as shown in Table 17. This number may appear to be high still, but it is caused by the poor forecast accuracy, now at 0.765.

	Original Analysis	**Special Causes Removed**
Consumption CoV	0.767	0.767

Forecast Error σ	3.098	1.668
Forecasted Demand μ	2.795	2.179
Forecast Error CoV	1.109	0.765
Future Demand μ	3.778	3.778
Forecast Error σ Projected Forward	4.188	2.891
Lead-Time	27.4 Weeks	27.4 Weeks
z	1.64 (95% SL)	1.64 (95% SL)
Safety Stock Level	37 Units 69 DOS	25 Units 46 DOS

Table 17: 7516250-20050 Key Statistics Comparison with Special Causes Removed

3.2.2.6.5. 4059021-903

The key statistics for part 4059021-903 are shown in Table 18. From a quick glance we can see that both the Consumption and Forecast Error CoVs are very high, near 2. This high Forecast Error CoV results in a safety stock level of 41 units (148 days of supply) that appears very high, but demand increases six times, e.g. 1.938 versus 0.308.

Consumption CoV	2.166
Forecast Error σ	0.615
Forecasted Demand μ	0.308
Forecast Error CoV	1.998
Future Demand μ	1.938
Forecast Error σ Projected Forward	3.871
Lead-Time	39.5 Weeks
z	1.64 (95% SL)
Safety Stock Level	41 Units 148 DOS

Table 18: 4059021-903 Key Statistics

In reviewing the actual historical consumption and past forecasts, as shown in Figure 30, we can see that the forecast is positively biased, i.e. being overdriven. In speaking with the demand planner, I learned that this part was also for a customer-specific MD-11 upgrade, but additionally these parts have huge yield problems. It is very possible that demand is being overdriven to account for quality issues that affect yield since in the organization there was no accountability for forecast accuracy.

It is very possible in this case that the quoted lead-time of 39.5 weeks is due to the yield issues with the part. And any compiling of safety stock would put more pressure on the manufacturing process that was responsible for the poor yield, so in this case meetings were recommended between the demand planners and the manufacturing planners to work through the yield issues and set a longer term strategy for safety stock.

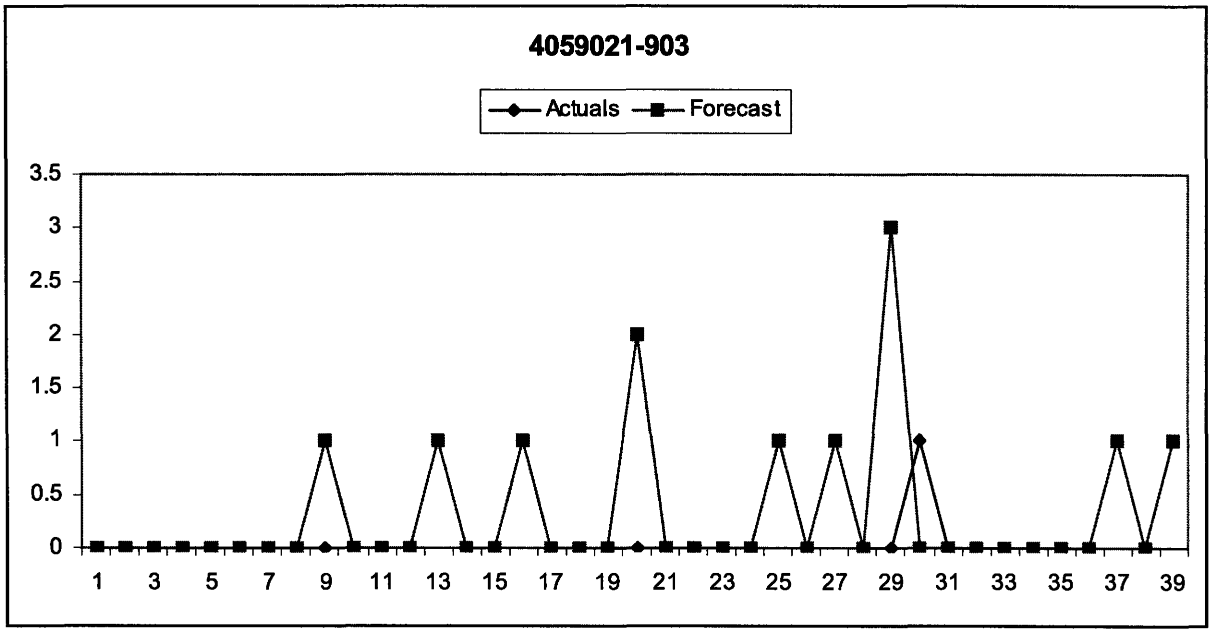


Figure 30: 4059021-903 Actual Historical Consumption versus Forecast

3.2.2.7. Step 7: Adjust

The safety stock levels were adjusted, as discussed in step 6 and the final set of recommendations were made to the demand planner and inventory and planning manager. A richer discussion follows in the following Results section.

3.2.2.8. Assumptions & Clarifications

The first clarification is that the lead-times used for the calculations are those that are captured within the planning systems. These are "cold start" lead-times and do not necessarily reflect the day to day reality, where planners have sufficient volume in the pipeline to work with a "hot start" lead-time.

Secondly, no supply uncertainty was used in the above calculations. Ideally, the safety stock should be calculated using both upstream and downstream uncertainty, but upstream data was not available.

The final assumption regards the snapshot for Consumption "Actual" data. This dataset represents a snapshot of what was planned for each week – taken at the first of the month. In other words, what was planned on a weekly basis, on the first day of the month, is what was used as a proxy for the weekly actual data. This assumption removes any issues with last minute production changes and removes any production problems.

3.2.3. Results

The pilot with ATR products at the APC highlighted a number of important results. First, after digging into the statistics it became clear that it was important to speak with multiple parties to find the context behind the numbers. In these examples, I spoke with demand planners and inventory and planning managers, but if I were looking at supply variability it would also be necessary to speak with production planners and planner-buyers (procurement managers). The context in an aerospace environment is equally important. Through discussions with the demand planner, I learned of parts on FAA hold, delayed NPIs, sales campaigns and manufacturing yield issues. Each of these affected the safety stock recommendations in some way.

The second major result of this exercise was the need for a structured process to set safety stock in a single echelon environment. More specifically, in November 2007 there was a push to set finished goods safety stocks, termed Strategic Inventory, across all sites as part of the SIOP initiative. The work that took place as part of this pilot rolled into that Strategic Inventory initiative.

3.3. Summary

This chapter discussed the application of the models from phases I and II of the Inventory Management Maturity Model to two different product centers at Honeywell Aerospace. After setting up the models described in Part II of this paper, we reviewed the results and discussed extensions to the models that have been created by individuals within Honeywell Aerospace.

With the Inventory Entitlement Model we saw that there is value in analyzing the macro picture - looking at an entire site's inventory level. This model gives a quick snapshot of where the site stands with respect to its planning parameters. On the other hand, with the Seven Step Rightsizing Process we saw the need to operate at a more micro, e.g. part number, level to account for all the extraordinary supply chain issues that we want to exclude from our safety stock calculations.

4. Part IV: Conclusion and Future Work

In the previous chapter, the case studies at Honeywell Aerospace demonstrated the models for phases I and II of the Inventory Management Maturity Model. First we saw how the Inventory Entitlement Model can be used to frame inventory levels in a manner that site management and executive manage appreciate and to identify inventory reduction projects. Then we saw a demonstration of the Seven Steps Rightsizing Process to recommend safety stock levels for finished goods. This chapter concludes this paper with final thoughts and recommendations for future research.

4.1. Conclusion

A maturity model was created that aids development of inventory and planning practices of an organization along the dimensions of people, process and technology. The models supporting the Inventory Management Maturity Model were applied to pilot projects during the author's internship at Honeywell Aerospace. Elements of the maturity model, e.g. the Inventory Entitlement Model and parts of the Seven Step Rightsizing Process, have been widely adopted by Honeywell Aerospace, while other elements are being adopted in parts.

We began this paper with a discussion of Honeywell Aerospace and their Sales, Inventory and Operations Planning initiative which set the backdrop for the author's internship. After discussing the motivation behind the author's work in greater detail, we looked at research relevant to form the foundation for a maturity model specific to inventory and planning practices. Chapter 2 introduced and described the Inventory Management Maturity Model and Chapter 3 discussed a number of case studies where we saw some of the benefits and limitations of the key supporting models for phases I and II of the maturity model.

4.2. Future Work

The work described in this thesis is only the beginning of a multi-year journey at Honeywell Aerospace that will see planning and inventory organizations increase their overall knowledge of inventory causes and effects. The journey, today, is described in the Inventory Management Maturity Model. All organizations have completed elements of phase I maturity and even developed important extensions that better suit their organizations. But there is more work to do with regard to phase II maturity. Honeywell Aerospace should run more rightsizing pilot projects to gain practice and learn about the drivers of stocking levels. It is only after this learning is gained that organizations can begin to tackle the challenges in phase III maturity, multi-echelon inventory optimization and network optimization.

The SIOP program has brought greater focus to planning. The SIOP assessment details where an organization is and what they need to develop to become best-in-class. Along the same lines, the models developed as part of this internship will enable inventory managers to play an important role in SIOP as those inventory managers learn to effectively quantify the impact of uncertainties on inventory levels. But to be truly a roadmap for development the Inventory Management Maturity Model needs to include an assessment element that clearly specifies how an organization is doing and what is needed to improve.

Bibliography

Aiello, J. L. (2008). *Rightsizing inventory.* Boca Raton: Auerbach Publications.

CMU SEI. (2007). Capability Maturity Model Integration (CMMI) Version 1.2 Overview. 1.2. Retrieved March 19, 2008, 2008, from http://www.sei.cmu.edu/cmmi/adoption/pdf/cmmi-overview07.pdf

CMU SEI. (2008). What is CMMI? Retrieved March 19, 2008, 2008, from http://www.sei.cmu.edu/cmmi/general/index.html

Cox, J. F., Blackstone, J. H., & APICS--The Educational Society for Resource Management. (2002). *APICS dictionary / editors, James F. Cox, III, John H. Blackstone, Jr* (10th ed.). Alexandria, VA: APICS.

Ettl, M., G.E. Feigin, G.Y. Lin, D.D. Yao. (2000). A supply network model with base-stock control and service requirements. *Operations Research, 48.*

George E. Plamatier, C. C. (2003). *Enterprise Sales and Operations Planning: Synchronizing Demand, Supply and Resources for Peak Performance*: J. Ross Publishing, Inc.

Glasserman, P., and S. Tayur. (1995). Sensitivity Analysis for Base-Stock Levels in Multiechelon Production-Inventory Systems. *Management Science, 41*, 263-281.

Graves, S., and S. Willems. (2000). *Optimizing the Supply-Chain Configuration for New Products.* Paper presented at the Proceedings of the 2000 MSOM Conference.

Graves, S. C., and S. P. Willems. (2000). Optimizing Strategic Safety Stock Placement in Supply Chains. *Manufacturing and Service Operations Management, 2*(1), 68-83.

Hammer, M. (2007). The Process Audit. *Harvard Business Review, 85*(4), 111-123.

Honeywell International Inc. (2008). *Form 10-K for HONEYWELL INTERNATIONAL INC.*

Hopp, W. J., & Spearman, M. L. (2001). *Factory physics : foundations of manufacturing management* (2nd ed.). Boston: Irwin/McGraw-Hill.

Hopp, W. J., Spearman, Mark L. (2004). To Pull or Not to Pull: What is the Question? *Manufacturing and Service Operations Management, 6*(2), 133-148.

Inderfurth, K. (1991). Safety stock optimization in multi-stage inventory systems. *International Journal of Production Economics, 24*, 103-113.

Inderfurth, K. (1993). Valuation of leadtime reduction in multi-stage production systems. *Operations Research in Production Planning and Inventory Control*, 413-427.

Inderfurth, K., and S. Minner. (1998). Safety stocks in multi-stage inventory systems under different service measures. *European Journal of Operations Research, 106*, 57-73.

Lee, H. L., and C. Billington. (1993). Material management in decentralized supply chains. *Operations Research, 41*, 835-847.

Lo, B. (2007). *Inventory Optimization in an Aerospace Supply Chain.* Massachusetts Institute of Technology, Cambridge.

Minner, S. (1997). Dynamic programming algorithms for multi-stage safety stock optimization. *OR Spectrum, 19*, 261-271.

Morgan, J. M., & Liker, J. K. (2006). *The Toyota product development system : integrating people, process, and technology.* New York: Productivity Press.

Optiant. Optiant Website. Retrieved March 2008, from http://www.optiant.com/

Rosenfield, D. B. (1994). *The Logistics Handbook: Section IV, Chapter 14: Demand Forecasting.* New York, NY: The Free Press.

Silver, E. A., Pyke, D. F., & Peterson, R. (1998). *Inventory management and production planning and scheduling* (3rd ed.). New York: Wiley.

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2003). *Designing and managing the supply chain : concepts, strategies, and case studies* (2nd ed.). Boston: McGraw-Hill/Irwin.

Simpson, K. F. (1958). In-process inventories. *Operations Research, 6*, 863-873.

Vollmann, T. E., Berry, W. L., & Whybark, D. C. (1997). *Manufacturing planning and control systems* (4th ed.). New York: Irwin.

Wanke, P. F., Zinn, Walter. (2003). Strategic Logistics Decision Making. *International Journal of Physical Distribution & Logistics Management, 34*(6), pp 466-478.

Whybark, D. C., and J. C. Williams. (1976). Material Requirements Planning Under Uncertainty. *Decision Sciences, 7*(4), 595-606.

Willems, S. P. (1996). *Strategic safety stock placement in integrated production/distribution systems.* Unpublished Thesis M.S. --Massachusetts Institute of Technology Sloan School of Management 1996.

Willems, S. P. (1999). *Two papers in supply chain design : supply chain configuration and part selection in multigeneration products.* Unpublished Thesis Ph.D. --Massachusetts Institute of Technology Sloan School of Management 1999.