# The Analysis and Optimization of the Alcoa Mill Products Supply Chain for European Customers

By
**Brian A. Urkiel**
B.S., Systems Engineering, United States Military Academy, 1993

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

MASTER OF SCIENCE IN MANAGEMENT
And
MASTER OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING

IN CONJUNCTION WITH THE LEADERS FOR MANUFACTURING PROGRAM AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June 2000



Signature of Author ______________________________
MIT Sloan School of Management
Department of Civil and Environmental Engineering
June 2000

Certified by ______________________________
Stephen C. Graves, Thesis Advisor
Co-Director, Leaders for Manufacturing Program
Sloan School of Management

Certified by ______________________________
James Masters, Thesis Advisor
Executive Director, Master of Engineering in Logistics (MLOG) Program
Engineering Systems Division

Certified by ______________________________
Joseph M. Sussman, Thesis Reader
Professor
Department of Civil and Environmental Engineering

Accepted by ______________________________
Daniele Veneziano, Chairman, Departmental Committee on Graduate Studies
Department of Civil and Environmental Engineering

Accepted by ______________________________
Margaret Andrews, Executive Director of the Master's Program
Sloan School of Management

# The Analysis and Optimization of the Alcoa Mill Products (AMP) Supply Chain for European Customers

By
**Brian A. Urkiel**

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

MASTER OF SCIENCE IN MANAGEMENT
And
MASTER OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING

## Abstract

This thesis examines the challenges of managing a global supply chain in a large, well-established organization and outlines certain techniques that can be utilized to achieve more effective supply chain management. The research was conducted at Davenport Works, which is part of the Alcoa Mill Products (AMP) Business Unit, and examined the business unit's global supply chain with its European customers.

The presence of inventory can hide many of the root cause problems within a supply chain and the project driver for this work was clearly inventory reduction. However, while excessive inventory is clearly a problem and organizations should strive to reduce unnecessary inventory as much as possible, there is an optimal amount of inventory that should be maintained and that amount is rarely zero. Inventory is held for a variety of reasons and can be utilized as a tool to countermeasure the primary factors that influence inventory requirements: customer demand, demand variability, production yield, production yield variability, lead time, lead time variability, and desired customer service levels. Alcoa utilizes inventory as a countermeasure within their supply chain for a variety of reasons. Customers are demanding increasing levels of service; and their demand patterns are variable. Replenishment lead times are long (on the order of months) and variable. Davenport Works is striving to achieve economies of scale; and their production yields are variable and often times deviate significantly from the customer's forecasted consumption rate.

Currently, high levels of inventory are being maintained throughout the supply chain; and desired customer service level targets are not being met. AMP has no formal methodologies to both characterize the reasons why inventory is being maintained and to determine what inventory requirements they need to satisfy each specific customer program. In addition, AMP is driving cost reductions throughout the entire organization. This is forcing the organization to justify the inventory they currently have and also putting pressure on the organization to reduce inventories throughout the supply chain.

This thesis has three primary objectives. Firstly, to provide a detailed analysis of the entire AMP supply chain for its European customers and articulate the reasons why AMP is maintaining inventory. This includes a discussion about supply chains, supply chain management, and the role of inventory in the supply chain. Secondly, to describe a methodology, which can be applied to engineer inventory levels for each product. The base stock model was used for this and is an excellent tool to demonstrate how supply chain variables impact inventory requirements, target areas for improvement, and quantify inventory requirements in a systematic manner. Thirdly, to provide recommendations to improve overall supply chain performance and optimize inventories.

| | |
|---|---|
| Thesis Advisors: | Dr. Stephen C. Graves, Professor, Sloan School of Management<br>Dr. James Masters, Engineering Systems Division |
| Thesis Reader: | Dr. Joseph Sussman, Professor, Department of Civil and Environmental Engineering |

*This page is intentionally left blank.*

# Acknowledgements

There are several people that I would like to acknowledge and thank for helping me conduct my research and complete this thesis. Their help, guidance and support made the internship experience a positive one and without them I would not have been able to complete this work.

First, I would like to thank my internship sponsor at Alcoa, Brian McConville. Brian put forth a great deal of effort to ensure the internship was set up for success from the beginning. He ensured I had access to all the resources I needed to complete my work and facilitated my smooth transition into the organization. Brian always made time to answer my questions and share his thoughts. I appreciated his efforts and valued his patience, insights and guidance.

There were so many people that helped me throughout the internship that they are too numerous to include. The organization provided an atmosphere that was helpful, open-minded, and cooperative. However, there are a few people I would like to mention. At Davenport Works I would like to thank Joe Velez, John Harrington, Sandy Madison, Phil Schubbe, Dan Robinson, Mark Schulenburg, Jeff Makoben, Julius Miller, Bruce Halter, Jim Erickson, Tracey Downey, Glenn Miller, Renee Oller, and Connie Fairchild. At the European Warehouse and the European Sales Office I would like to thank Alex Tattersall, Robert Beerten, Veronique Badel, Lia Maiorano, Paulo Guala, Manfred Neuenschwander, Helmut A. Steinkusch, and Beatrice ???.

I would also like to thank my advisors at MIT for their help, guidance and support. Steve Graves was extremely helpful through numerous emails, face-to-face meetings, and on-site visits. I would also like to thank my other advisor, James Masters and my thesis reader Joe Sussman for their comments and support.

Finally I would like to thank the Leaders for Manufacturing Program and acknowledge the support I received through the current students, program office, and past theses of LFM students.

*This page is intentionally left blank.*

## Table of Contents

# CHAPTER ONE: Introduction

## 1.1: Thesis Organization

The thesis is organized into six chapters; and each chapter is written with the intent of being its own stand-alone document. Chapter one provides some background information about the Alcoa Mill Products (AMP) Business Unit (BU), describes the problem development, project approach and the agreed upon objectives for the project. Chapter two draws upon existing literature and provides a framework to discuss supply chains, supply chain management, inventory and the role of inventory within the supply chain. Building upon the framework established in chapter two, chapter three gives an in-depth description of the AMP supply chain for its European customers. Chapter four provides a customer analysis on the three largest European customers within AMP as well as the breakdown of the different products that AMP provides to these customers. Chapter five describes the development of the methodology to engineer inventory levels by product. Chapter five also describes the major sources of variability within the AMP supply chain and highlights the impact of variability on inventory requirements and supply chain performance. Chapter six identifies key learnings and provides a breakdown of various recommendations for improvement and future work.

**The numbers presented in this thesis are disguised to protect AMP.**

## 1.2: Background Information

This thesis examines the challenges of managing a global supply chain in a large, well-established organization and outlines certain techniques that can be utilized to achieve more effective supply chain management. The research was conducted at Davenport Works, which is part of the Alcoa Mill Products (AMP) Business Unit, from June 1999 through December 1999 and examined the business unit's global supply chain with its European customers. The primary components of the supply chain include the Davenport Works Manufacturing Facility, a European Sales Office, the Alcoa International Service Center (AISC) in Europe (which consists of a large warehouse), and various customers (approximately 43) located throughout Europe.

### 1.2.1: Alcoa Mill Products (AMP) Business Unit Overview

Alcoa Mill Products (AMP) is one of 24 business units within Alcoa and produces the widest variety of aluminum sheet and plate products in the world. AMP is a global organization that has over 4,000 employees operating in locations in the United States and Europe. The AMP headquarters is located at Davenport Works and AMP has three primary manufacturing facilities that are located in Bettendorf, Iowa (Davenport Works); Lancaster, Pennsylvania; and Texarkana, Texas.

The manufacturing facilities within AMP provide products for four major markets: Aerospace; Automotive Systems; Building, Home & Communications; and Distribution. My analysis primarily focused on plate and sheet products being produced for European customers involved in the Aerospace market. As a result, the majority of the products had relatively high profit margins in comparison to other aluminum plate and sheet products.

Over the past few years AMP has been performing extremely well within the European aerospace market due to the aerospace industry's steady growth. Due to this steady inflow of high profits, there had not been a strong emphasis on cost reduction and in particular, the reduction of inventories across the supply chain. The mindset had been if "X" amount of inventory was needed to achieve the high profit levels that were being achieved, then it is acceptable to carry "X" amount of inventory even if this level of inventory is sub-optimal. However, due to the cyclical nature of the aerospace industry and the focus on continuous improvement activities, AMP is beginning to instill a cost conscious mindset across the business unit. As a result, the high levels of inventory that are being maintained throughout the supply chain (in particular within the European warehouse) are being questioned; and there is strong impetus to significantly reduce these inventories to achieve cost reduction objectives. This is forcing the organization to develop both an understanding of why they are maintaining inventory for their European customers and a methodology to engineer inventory levels by product so they can determine how much inventory they actually need to satisfy their customers requirements. The recent emphasis on cost reduction and the focus on inventory in the AMP supply chain were extremely strong driver's for this project.

### 1.2.2: Davenport Works Overview

The bulk of the research for this project was conducted at the Davenport Works manufacturing facility. Davenport Works is considered the "flagship operation" within AMP and serves as the business unit's primary manufacturing facility. This thesis considers only products produced at this facility.

Davenport Works is a truly amazing manufacturing facility. Davenport Works has been in operation since 1948 and is the world's largest aluminum fabricating facility. It exceeds one mile in length and contains over 128 acres (5.5 million square feet) under one roof. The facility operates 24 hours a day, 7 days a week, 365 days a year and employs over 2600 Alcoans. The facility produces 11,000 different product specifications from over 110 different alloys for 1100 customers around the world. The custom-made products range in thickness from 0.006 inches to 20 inches, widths from 0.75 inches to 210 inches, and lengths of up to 1260 inches. These numerous custom-made products can be divided into two large product groups, plate products and sheet products. Plate products have a minimum thickness of 0.250 inches and can be heat-treated or non heat-treated and mill finished or non-mill finished. Sheet products range in thickness from 0.006 inches to 0.249 inches and can be formed into flat sheets or coils. The products examined in this project consisted of a mix of both plate and flat sheet products.

## 1.3: Development of the Problem and Project Objectives

The development of both the problem and the project objectives was a dynamic process. Within the Alcoa Business System the approach to solving a problem involves developing a business case for the project (project driver), developing a current condition, and then developing a target condition (essentially a re-statement of the business case).

When I initially came to Davenport Works there was tremendous emphasis and concern within the business unit on the high levels of inventory currently being maintained in the AMP supply chain for European customers. Since the overwhelming majority of metal (over 98%) for continental Europe flows through the European warehouse, the focus was geared towards this facility. Due to the cost cutting measures within AMP, the cyclical nature of the aerospace market, and the focus on continuous improvement activities; inventory reduction was at the forefront of everyone's mind. As a result, there was a very explicitly defined initial business case for the project.

**Business Case for the Project (PROJECT DRIVER):**
Try to reduce the amount of inventory currently being maintained for European customers within the AMP supply chain (specifically the inventory being maintained in the European warehouse).

Given this project driver, I established a systematic approach to the problem. First, I set out to establish the current condition of the AMP supply chain in order to gain an understanding of the supply chain issues and investigate the root causes of the current inventory being maintained in the supply chain. I needed to develop an understanding of the AMP supply chain to accurately define the problem. I thought that this was particularly important for AMP because there was no one individual within AMP that had 100% visibility of the entire supply chain. The clearly laid out current condition of the AMP supply chain provided a detailed framework within which analysis of supply chain issues could be accomplished. Second, I wanted to develop and apply a simple inventory model (a variation of the Base Stock Model) to characterize inventory requirements in terms of customer demand, lead time, production processes (yields, constraints, flowpaths), customer service levels, and variability. There seemed to be a lack of a detailed inventory control system (that spans the entire supply chain) and a model or methodology would help establish some organizational consistencies with regard to inventory. Furthermore, the model helps develop a better understanding concerning the reasons for maintaining inventory and how other variables within the supply chain (customer demand, lead-time, production processes, customer service level and variability) impact inventory requirements.

As the current condition became clearer and we were able to develop a better understanding of inventory and supply chain management, I was able to develop a target condition, which differed from the initial project driver.

**Target Condition (A re-statement of the business case.):**
Satisfy the customer requirements that we have agreed to provide in the most efficient manner possible based on the current condition of the supply chain.

It is interesting to note that inventory is not mentioned within the target condition. The target condition tries to re-establish the focus on the customer rather than focusing on internal problems that are transparent to the customer. The customer does not care how much inventory you are carrying, the customer cares about whether you satisfy the requirements that have been agreed upon in the most efficient manner possible.

In order to provide focus and clearly establish what we wanted to accomplish, I jointly established three primary objectives for the project with key stakeholders within AMP. It was important to jointly establish the primary objectives to ensure that I was working on something that would provide value to Alcoa. Throughout the process, I structured my work around three agreed upon primary objectives.

**Primary Objectives of the Project:**
1. Develop an understanding of why AMP maintains inventory for its European customers.
2. Develop a methodology for AMP to "engineer" inventory levels (by product).[1]
3. Explore tactics to improve the AMP supply chain and optimize inventories.

## 1.4: Chapter Summary

AMP is a large organization that operates on a global scale and is faced with the challenge of managing an extensive and complex supply chain. Similar to many other major manufacturing companies in the world today, Alcoa is trying to reduce costs, to operate more efficiently, and to satisfy the needs of their customers in the most effective way possible. More effective management and utilization of the supply chain is a means to achieve these goals. Inventory management and control are a challenge within supply

[1] "Engineered inventory levels" is a phrase utilized within AMP. It means that appropriate inventory levels are calculated based on a formal methodology and data rather than individual experience and intuition.

chain management and are often identified as a major problem within many manufacturing organizations. When I initially arrived at AMP, inventory was certainly viewed as a problem. However, inventory is usually a symptom of other root cause problems within the supply chain. Developing a systematic approach to the problem was critical in being able to identify and address root cause problems within the supply chain. Once the root cause problems can be identified and addressed appropriately, the problems associated with inventory management and control can be eliminated.

# CHAPTER TWO: Supply Chain Management and the Role of Inventory in the Supply Chain

Supply chain management is one of the most prevalent business "buzz-words" being utilized in industry today. Supply chain management is being promoted as a way an organization can operate more efficiently, reduce costs and achieve significant competitive advantages. This chapter tries to define supply chain management; what comprises a supply chain; what is inventory and its role in the supply chain; and how supply chain management can help an organization achieve significant competitive advantages.

## 2.1: The Supply Chain

I first went to existing literature on the subject to develop a sense of how researchers and academics seem to characterize supply chains and supply chain management. Here are various definitions of supply chain and supply chain management from a variety of sources:

> *"Supply chain management is the integration of business processes from end user through original suppliers that provides products, services and information that add value to the customer."*[2]

> *"Supply-chain management is a collaborative based strategy to link cross-enterprise business operations to achieve a shared vision of market opportunity. It is a comprehensive arrangement that can span from raw material sourcing to end consumer purchase."*[3]

> *"The delivery of enhanced customer and economic value through synchronized management of the flow of physical goods and associated information from sourcing to consumption."*[4]

> *"The broadest definition of a supply chain is any sequential set of business operations leading from raw material through conversion processes, storage, distribution, and delivery to an end customer. Product flows sequentially*

---

[2] Lambert, Stock and Ellram, 504.

[3] Quinn, 2. This definition was in the Quinn article but taken from Professor Donald J. Bowersox of Michigan State University.

[4] Larson and Rogers, 2. This definition was in the Larson and Rogers article but taken from Professor Bernard J. LaLonde.

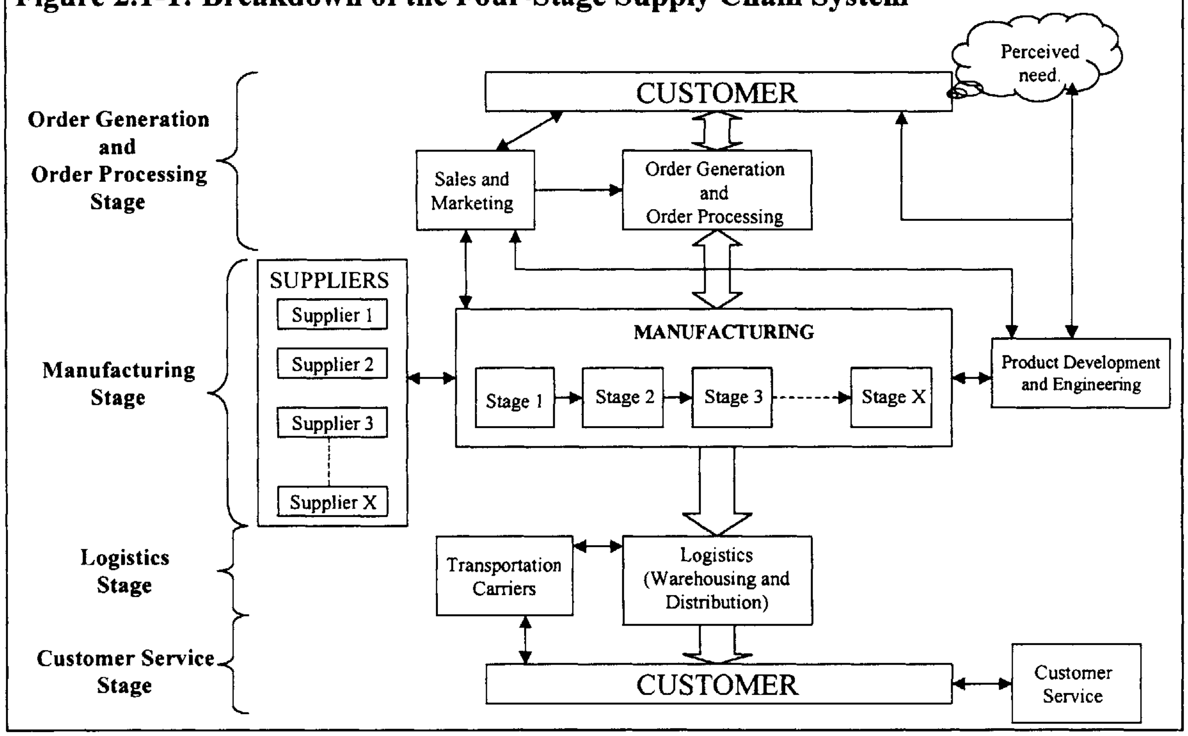
*through the system from one level to another. Information in the form of orders flows back the other way.*"[5]

*"Supply Chain encompasses all those activities associated with moving goods from the raw materials stage through to the end user.*"[6]

These definitions are high level and provide a general sense of supply chain management. But supply chain management is complex and it is critical to first define the framework of a supply chain before attempting to address supply chain management.

I view the supply chain as a system that can be broken down into four different stages that begins with a perceived need by the customer and extends to the customer service provided to the customer after delivery of the product and/or service. Given its broad scope, the supply chain is effected by and involves interactions between customers, sales, marketing, manufacturing (to include product development and engineering), logistics (to include warehousing and distribution), and customer service. Figure 2.1-1 provides a graphical representation of the four-stage supply chain system.

**Figure 2.1-1: Breakdown of the Four-Stage Supply Chain System**




---

[5] Layden, 2.
[6] Larson and Rogers, 1-2.

### Order Generation and Order Processing Stage

The supply chain starts with the generation of orders by customers to satisfy perceived needs that the customer have. If orders cannot be generated, then there will be no opportunities to make money. Order generation involves a multitude of activities and interactions. Developing a relationship with the customer to determine their needs and how the organization can best meet them is critical. This function is most often performed by the sales and marketing groups through two-way interaction with the customer. In addition, the product development and engineering groups play a key role in this stage through their interactions with both the customer and the sales and marketing groups. Since product development and engineering are responsible for developing the solutions to the customers needs, it is essential that they are involved in this stage of the supply chain. It is important to note that sales, marketing, product development and engineering must continually communicate with manufacturing to ensure that the organization can produce what the customers want when they want it.

Once the orders are generated from customer needs, they need to be processed in a way that enables the other stages of the supply chain to satisfy the orders. Order processing primarily revolves around information flow and information management. Sometimes customer orders may be satisfied from an existing stock; and the pertinent information must be transferred to key players in the logistics stage of the supply chain to ensure the appropriate products are delivered to the customer. In a more traditional sense, customer orders are sent to manufacturing in a timely manner with all pertinent information clearly stated so manufacturing can initiate production. The customer order must be tracked from its origin until the order is complete (i.e. the customer need has been satisfied). In addition, order processing involves capturing customer data so that the information can be utilized in a useful way (i.e. to improve forecasting accuracy, to quantify demand variability, and to identify potential customers for new products).

### Manufacturing Stage

The manufacturing stage is where most of the emphasis on the supply chain is focused. This is the stage where products are produced to satisfy the orders generated in the first stage. The actual manufacturing part of this stage may also involve many sub-stages. The product may go through several different operations and processes before it reaches its end state. Each separate operation can be considered as an individual sub-stage within the overall manufacturing stage.

The manufacturing group must also continually interact with the sales, marketing, product development, and engineering groups; external suppliers; as well as key individuals in the logistics group. Sales and marketing is the manufacturing group's link with the customer, so it is crucial to ensure they are constantly communicating to ensure customer needs are being satisfied. Manufacturing must also develop relationships with their suppliers. Manufacturers and suppliers must continually share information to ensure the required resources are available when needed throughout the production process. Sometimes there is a separate procurement or materials group that handles this responsibility and deals with suppliers. Finally, manufacturing needs to work with the logistics group to ensure their products are delivered to the customer when promised.

**Logistics Stage**

The logistics stage is responsible for delivering the products that are produced in the manufacturing stage to the end customer. This stage may involve the use of warehouses or distribution centers to hold the product until the customer's desired delivery date. In addition, distribution may involve interactions with outside entities such as transportation carriers (truck, rail, ship, and air), distributors, third party logistics providers, and end customers. The logistics stage may also involve participation at the front end through the delivery of raw materials and components.

**Customer Service Stage**

I have included a customer service stage in my breakdown of the supply chain because the organization needs to maintain a relationship with the customer even after the product or service is delivered. Repairs may be needed, the customer may have questions that need to be answered by the manufacturer, and most importantly an existing customer is a potential future customer for new products. By providing the customer with excellent service and maintaining the relationship with the customer even after the product has been delivered, the organization gains valuable customer information that can be useful in the future as well as helping to build a positive reputation within the marketplace.

## 2.2: Supply Chain Management

The purpose of supply chain management is to manage the components of the supply chain and manage the flow of information, materials and services across the supply chain in order to achieve the end goal of customer satisfaction in the most efficient means possible. There are some critical concepts associated with supply chain management:

- The supply chain is a system and therefore, effective supply chain management requires the ability to manage from a systems approach. A systems approach means that all the cross-functional interactions need to be understood in terms of how they affect one another. Each interaction must be viewed from the perspective of how the entire system is affected rather than in isolation. While it may appear that individual operations are being optimized, the entire system may be being suboptimized.[7] Even though managers may only be responsible for a particular segment of the supply chain, they must understand how all the stages of the supply chain interact with one another to achieve system wide efficiencies.[8]

- The supply chain involves multiple entities both internal and external to the organization that must operate collaboratively. In order to function effectively, long-term relationships must be established and managed. Relationship management must be undertaken to achieve the high levels of trust and commitment that are necessary to share information and facilitate the smooth flow of information and materials across the supply chain.[9]

---

[7] Lambert, Stock, and Ellram, 7-10.
[8] Quinn, 2.
[9] LaLonde and Masters, 5-6.

- Information technology is a key enabler to effective supply chain management.[10] In particular, the use of electronic data interchange (EDI), the Internet, and enterprise resource planning (ERP) can greatly enhance the speed and ability of an organization to manage information seamlessly across multiple entities of the supply chain.[11]

Supply chain management has been receiving a lot of attention and is seen as a way organizations can gain a competitive advantage. In addition, most organizations can drastically improve the way they manage their supply chains. A possible reason for this is due to the complexity of many organization's supply chains; the entire supply chain system is not understood across the organization. As a result, supply chain management never receives high priority or adequate attention unless there is a crisis. Here are some of the major challenges that managers within supply chains must deal with:

- I think the number one challenge managers face in the supply chain is the presence of variability. There are numerous sources of variability throughout the supply chain and the organization must first understand them before they can be eliminated. Unfortunately, the tendency is to develop ways to deal with the variability, rather than striving to understand it and then work on ways to reduce or eliminate it (i.e., failure to perform root cause analysis).[12]

- Many organizations fail to implement supply chain metrics and as a result, the overall performance of the supply chain suffers. Each entity in the supply chain is usually managed independently with specific objectives. These objectives may not be aligned with the objectives of other entities in the supply chain and in some cases; objectives between different entities are in direct conflict.[13] Organizational barriers and poor coordination magnify the reduced performance of the entire supply chain.[14]

- Managing the flow of information is critical to any successful supply chain. Often times, information is difficult to obtain in a timely manner and sometimes the

---

[10] LaLonde and Masters, 14-15.
[11] Larson and Rogers, 4.
[12] Lee and Billington, 4.
[13] Lee and Billington, 2.
[14] Lee and Billington, 6-7.

necessary information is not being captured (in particular, information on variability). Information technology systems are being utilized to assist organizations in managing their data. However, the supply chain contains many different entities and often the databases being maintained by different entities in the supply chain are either not linked with one another or the data is not compatible.[15]

- Many firms operate with inadequate inventory management systems.[16] In the past (before the increases in computing power) there was no clear-cut analytical way to engineer inventory levels by product. As a result, firms tended to rely on a combination of experience and intuition in managing their inventories.[17] Today, organizations have the capabilities to collect accurate data and then apply quantitative techniques to perform a thorough supply chain analysis.[18] Inventories can be engineered by product based on the current condition of the supply chain. Benchmarking is often a useful starting point in developing inventory management systems.

## 2.3: Inventory in the Supply Chain

Most individuals have a negative bias towards inventory and focus all their efforts on reducing inventory and hence eliminating unnecessary costs within the supply chain. Although it is correct to eliminate unnecessary costs within the supply chain, eliminating inventory is not always the right answer. There is an optimal amount of inventory that should be maintained within the supply chain; and it is incorrect to assume that zero inventories are optimal and reduction of inventories is always better. ***The purpose of inventory is to serve as a countermeasure within the supply chain against obstacles that prevent us from achieving our goal of satisfying the customer requirements in the most efficient manner possible***. Inventory is an important tool, that when used correctly, can reduce the total costs throughout the supply chain and improve the levels of service that can be provided to the customer.

[15] Lee and Billington, 3.
[16] Lee and Billington, 5.
[17] Davis, 3.
[18] Davis, 12.

### 2.3.1: What is inventory?[19]

Inventory represents a tremendous investment for most manufacturing companies. However, not all inventories are the same and the inventory takes on different characteristics as it moves through the production process. Most of the manufacturing literature characterizes inventory as either raw materials inventory, work in process (WIP) inventory, or finished goods inventory (FGI).

**RAW MATERIALS INVENTORY**: Raw materials are physical items that are required as inputs at some stage in the production process; and without them end products or subassemblies cannot be produced. At Davenport Works, raw materials are aluminum and other metals, which are mixed and then cast to form ingots of various sizes and alloys. These raw materials are considered commodities; and their prices fluctuate based on market conditions. Raw material sourcing can be difficult to perform effectively because there is variability associated with raw material prices, production yields and customer demand patterns. It is a challenge every year for AMP to determine how much raw material they will need to ensure they can satisfy all customer demand while not being forced to hold excess raw material.

**WORK IN PROCESS INVENTORY (WIP):** WIP inventory represents material that has entered the production process but still requires more processing before it is considered complete. WIP differs from raw materials in the sense that the item has already entered the production process and is either waiting to be processed or being processed within the manufacturing system. WIP inventory becomes finished goods inventory once all processing and testing on the material has been completed.

WIP inventory levels are critical to the performance of any manufacturing system. There is a fundamental relationship between WIP levels, cycle time and throughput.

[19] This section was developed from information from three different sources (Factory Physics (Hopp and Spearman), pages 554-557; Production and Operations Analysis (Nahmias), pages 213-219; and The Fundamentals of Logistics Management (Lambert, Stock and Ellram), pages 112-166)

According to Little's Law, at every level of WIP in the system, the ratio of WIP to cycle time yields the throughput of the process.[20]

| | |
|---|---|
| **Little's Law:** | **Throughput = (WIP) / (Cycle Time)** |

Little's Law demonstrates that inventory is critical to a manufacturing system. It clearly shows that a manufacturing system cannot operate with zero inventories because zero inventories imply zero WIP, which results in zero throughput.[21] Davenport Works utilizes Little's Law extensively to operate their manufacturing systems more efficiently. Assuming that throughput remains constant, you can reduce cycle time if you reduce the amount of WIP in the system.

WIP inventory represents a significant portion of inventory within Davenport Works simply because lead times are long and product routings are complex. Therefore, any supply chain analysis and inventory management system must take this inventory into account. The tendency is to focus on raw materials inventory or finished goods inventory because their magnitude can be more easily determined since those types of inventories are usually consolidated in a smaller number of locations. WIP on the other hand is located in numerous locations throughout the manufacturing facility in many different forms. Therefore, WIP has less visibility and is generally harder to keep track of. Davenport works has developed internal tracking systems to continuously monitor WIP levels throughout the facility. Utilizing the concepts presented in Little's Law, Davenport Works has achieved major cost reductions through WIP reductions which have allowed them to reduce cycle times while maintaining required levels of throughput.

**FINISHED GOODS INVENTORY (FGI):** FGI are items that have completed the production process but have not actually been sold to the customer. FGI is usually the type of inventory that gets the most attention and is the target of most inventory reduction

[20] Hopp and Spearman, 231-232. They define cycle time for a given routing as "the average time from release of a job at the beginning of the routing until it reaches an inventory point at the end of the routing" (page 223). They define throughput as "the average output of a production process (machine, workstation, line, plant) per unit time (page 223).
[21] Hopp and Spearman, 556.

initiatives. This is primarily because FGI is the most expensive type of inventory since it represents material with the most time, money, and value invested in it.

FGI can be further subdivided into five separate categories: cycle stock; safety stock; in-transit inventory; seasonal stock and dead stock. **Cycle stock** represents inventory that is consumed during each replenishment cycle (represented as a saw tooth in most inventory diagrams). The level of cycle stock fluctuates throughout the replenishment period (the time between replenishments) and is dictated by the order quantity. **Safety stock** represents inventory that you keep in excess of cycle stock to account for variability in the supply chain (demand, lead time, production yield) and to reduce the probability of a stockout. The greater the variability in the supply chain, the more inventory you need to maintain in terms of safety stock. **In-transit inventories** are inventories that are being moved from one location to another. The inventory may be moving to a storage facility or the end customer. **Seasonal stock** represents the inventory that is accumulated before a seasonal period begins.[22] **Dead stock,** or obsolete inventory, represents items in inventory for which there has been no demand registered for a specified period of time.[23] The removal of dead stock is a method to quickly reduce inventory costs and achieve immediate positive results from any supply chain analysis project. However, the removal of dead stock requires a write-off that results in a potentially significant financial hit to the organization.

It is important to note that the categorization of inventory into one of the four categories is situational dependent. Raw materials for one stage of the production process may be considered as finished goods for another stage of the production process. For example, at Davenport Works, an individual associated with the mill flow stage of the production process would consider aluminum ingots as raw materials, but they are considered as finished goods from the perspective of an individual in the ingot plant.

[22] Lambert, Stock and Ellram, 119.
[23] Lambert, Stock and Ellram, 120.

### 2.3.2: What are the reasons for holding inventory?

There are several reasons why a firm may choose to hold inventory; and the relative importance of each reason varies based on the particular situation.

**ECONOMIES OF SCALE**: The basic idea behind economies of scale is that as the number of items produced per production run increases, the per unit cost decreases. Economies of scale lead to an increase in the amount of cycle stock a firm maintains. There are generally three major areas where organizations try to achieve economies of scale: Procurement; Production; and Transportation.[24]

Economies of scale in procurement are generally applicable when dealing with raw materials inventory and possibly WIP inventory. They can result when suppliers offer firm's quantity discounts for certain items. When this occurs it may be beneficial for firms to purchase large quantities and then maintain inventory because the savings they realize from the discount will more than offset the associated inventory costs.

Economies of scale in production occur when processes operate more efficiently when they are run at their own pace. This may result in longer production runs or processes that run more efficiently when producing large quantities rather than small quantities. In situations where you are trying to achieve economies of scale in production, total costs decrease as you produce larger quantities of items in each run. This is a major issue concerning Davenport Works because the equipment at Davenport Works was designed to produce items in large quantities rather than smaller quantities. Furthermore, orders are produced from full ingots; and if there is no opportunities to satisfy multiple orders from a single ingot, then overage is produced. Since Davenport Works wants to produce in increments of a complete ingot to achieve economies of scale, the task of producing small quantities (i.e., smaller than the production yield of an ingot) for particular customers has significant recovery and inventory ramifications.

Transportation economies of scale are designed to reduce transportation costs and are achieved by delivering products to customers in full containers via full truckloads or

[24] Lecture notes from Logistics Systems (1.260).

full shiploads. From a cost perspective, it is more efficient to transport material in full trucks, ships or containers rather than partially filled trucks, ships or containers. This mindset can lead to holding inventory until full loads can be created. Furthermore, although economies of scale in transportation help reduce costs, they do not promote higher levels of customer service because the shipment of products may be delayed until full container loads can be assembled.

**UNCERTAINTY AND VARIABILITY**: I think uncertainty and variability are the largest reasons why a firm needs to hold inventory (in particular safety stock). Inventory serves as a countermeasure for uncertainty and variability in the supply chain. Therefore, increased levels of uncertainty and variability lead to an increased amount of safety stock that must be maintained. This inventory is particularly important because it is unknown what the ramifications are if the customer is not given what they want when they want it. There may be significant backorder costs, lost sales costs, or even lost customer costs.

Uncertainty of demand is often cited as the primary source of uncertainty. The customer can change their forecasted demand for a variety of reasons (changing market conditions, their own production problems, etc.) and the manufacturing firm must be able to react. There may also be uncertainty in the production processes that also requires inventory to be maintained as a countermeasure. This is particularly applicable to Davenport Works because many of the flowpaths contain processes that result in variable production yields. This production yield variability can also affect production lead times because more or fewer production runs are needed to achieve the desired customer demand quantity. To a lesser extent (in the case of AMP), uncertainty and variability in supply can also lead to increased amounts of inventory. In order to produce the products for its customers, a firm needs certain raw materials. Sometimes, firms choose to maintain additional inventories to account for potential problems in obtaining necessary raw materials needed for production.

**LEAD TIME**: Inventory being held to compensate for long replenishment lead times is significant for AMP because replenishment lead times are on the order of four months. When the lead time the customer desires (the time from when the customer places an order to the time the customer requests receipt of the order) is less than the lead time for the manufacturer, inventory must be maintained in the system to compensate for this. Lead-time from the manufacturer consists of order entry flow time, production flow time, delivery flow time, and any lead-time resulting from current booking and capacity constraints. The additional lead-time resulting from current booking and capacity constraints poses a significant problem in managing the supply chain for AMP (i.e., when there is no available capacity to manufacture products for new orders until a certain period of time).

**SERVICE LEVEL**: Customers are demanding increasing levels of service. In order to provide the customers with high levels of service, the manufacturer needs to maintain increased amounts of inventory.

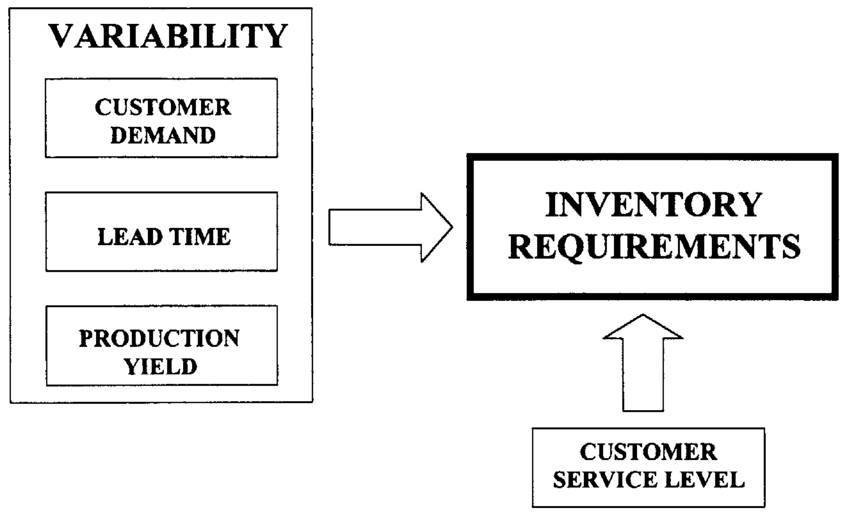
### 2.3.3: Key insights about inventory for supply chain management.

The first key insight concerning inventory and supply chain management is that inventory requirements are simply a by-product of the supply chain. Inventory is the result of other problems within the supply chain and those problems must be minimized or eliminated before inventory can be reduced.[25] Too often the focus is on the inventory itself rather than the factors that cause inventory. We discussed previously the reasons why organizations maintain inventory, however, these reasons are manifested in the following quantifiable variables: customer demand; demand variability; lead time; lead time variability; production yields; yield variability; and desired customer service levels. Once these factors that are causing the need for inventory are understood and managed, inventory can be eliminated in a rational manner.[26] Inventory requirements are dictated by the designated customer service level; customer demand; lead time; production yield; and the variability associated with customer demand, lead time, and production yield. Figure 2.3-1 shows the primary factors impacting inventory requirements (customer demand, demand variability, lead time, lead time variability, production yield, yield variability, and desired customer service level).

---

[25] Inman, 3.
[26] Inman, 3.

**Figure 2.3-1: Primary factors influencing inventory requirements.**

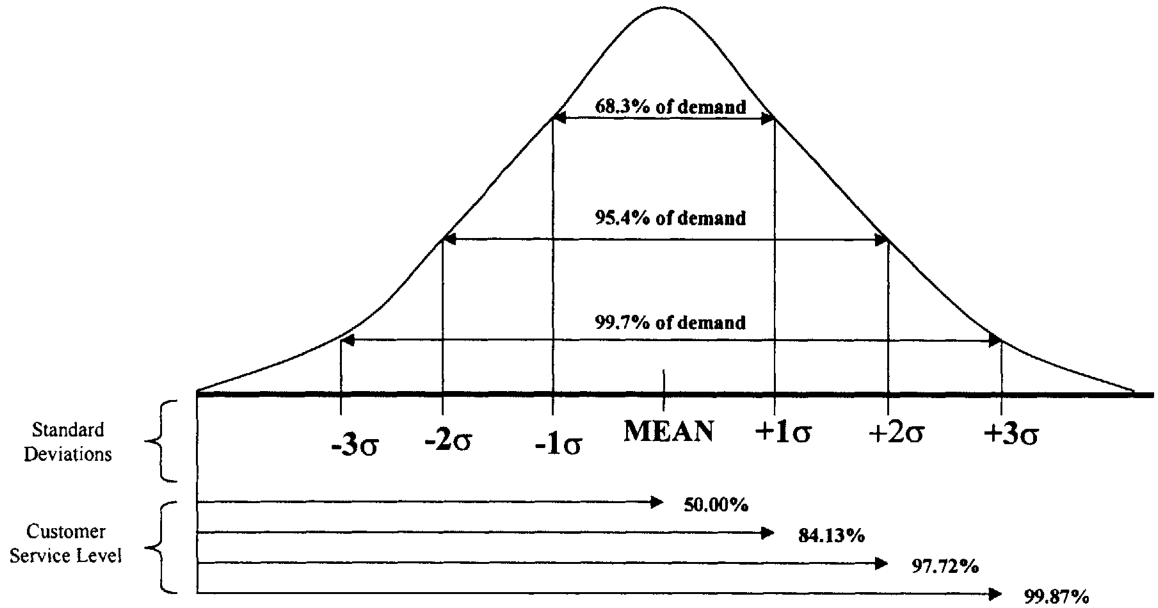



This is the perspective from which inventory requirements need to be evaluated. As will be shown with the base stock model, if you try to reduce inventory without addressing one of the key parameters that are dictating the inventory requirements, then the result will be a decrease in the level of customer service. An important exception to this rule is when you are removing dead stock from the supply chain.

A second key insight about inventory in the supply chain concerns the relationship between safety stock and customer service level.[27] We often assume that demand for a particular product roughly follows a normal distribution. Given this assumption we can assess how much safety stock we need to maintain in order to achieve a desired level of service. The desired customer service level dictates the amount of safety stock needed in terms of multiples of the standard deviation of demand. Figure 2.3-2 shows a graphical representation of this relationship.

[27] I am defining customer service level as the probability that a customer order is satisfied within the replenishment lead time (i.e, the probability that a stockout does not occur during lead time). This definition is taken from Jim Masters (Lecture notes from 1.260: Logistics Systems).

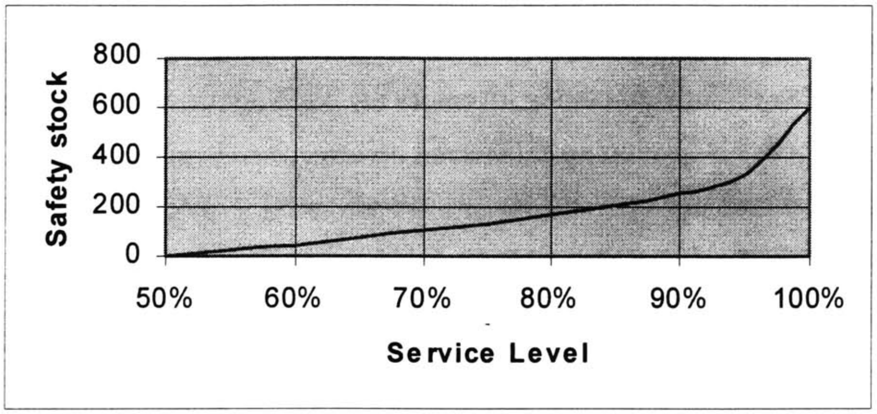
**Figure 2.3-2: Customer service levels based on the normal distribution.**[28]




In addition, the relationship between inventory and service level is not linear. This is a critical insight. Often times, individuals believe that in order to increase service levels from 90% to 95% or 95 % to 99%, the amount of inventory you need to carry will correspondingly increase by 4-5%. This is incorrect. As an organization tries to provide higher levels of service (especially in excess of 90% service levels) the amount of inventory they will need to maintain in the supply chain increase significantly. Figure 2.3-3 shows a graphical example of the impact on safety stocks when service level exceeds 90%.

[28] Lambert, Stock, and Ellram, 142.

**Figure 2.3-3: The non-linear relationship between safety stock and service level.**




The final insight about inventory is that inventory hides problems within the supply chain. The example of rocks in a stream is often used to show how inventory (the water) can hide supply chain problems (the rocks). As you lower the level of the water (reduce inventories) the rocks (supply chain problems) become exposed and can then be removed.[29] This example shows that in some cases it may be beneficial to reduce inventories to try to identify production problems. This technique is particularly applicable to large job shops, such as Davenport Works, where complexity and numerous product routings make it difficult to pinpoint problems. It should be noted that these inventory reductions should be done incrementally rather than in large doses all at once.[30]

## 2.4: Chapter Summary

The supply chain is a system that can be broken down into four stages: the order generation and order processing stage; the manufacturing stage; the logistics stage; and the customer service stage. The purpose of supply chain management is to manage the components of the supply chain and to manage the flow of information, materials and services across the supply chain in order to achieve the end goal of customer satisfaction in the most efficient means possible. Supply chain management is complex; and there are numerous challenges that managers must deal with in handling supply chain issues.

[29] Inman, 4.
[30] Inman, 4.

Many organizations manage their supply chains sub-optimally and therefore, supply chains are receiving more attention and being seen as a source of competitive advantage.

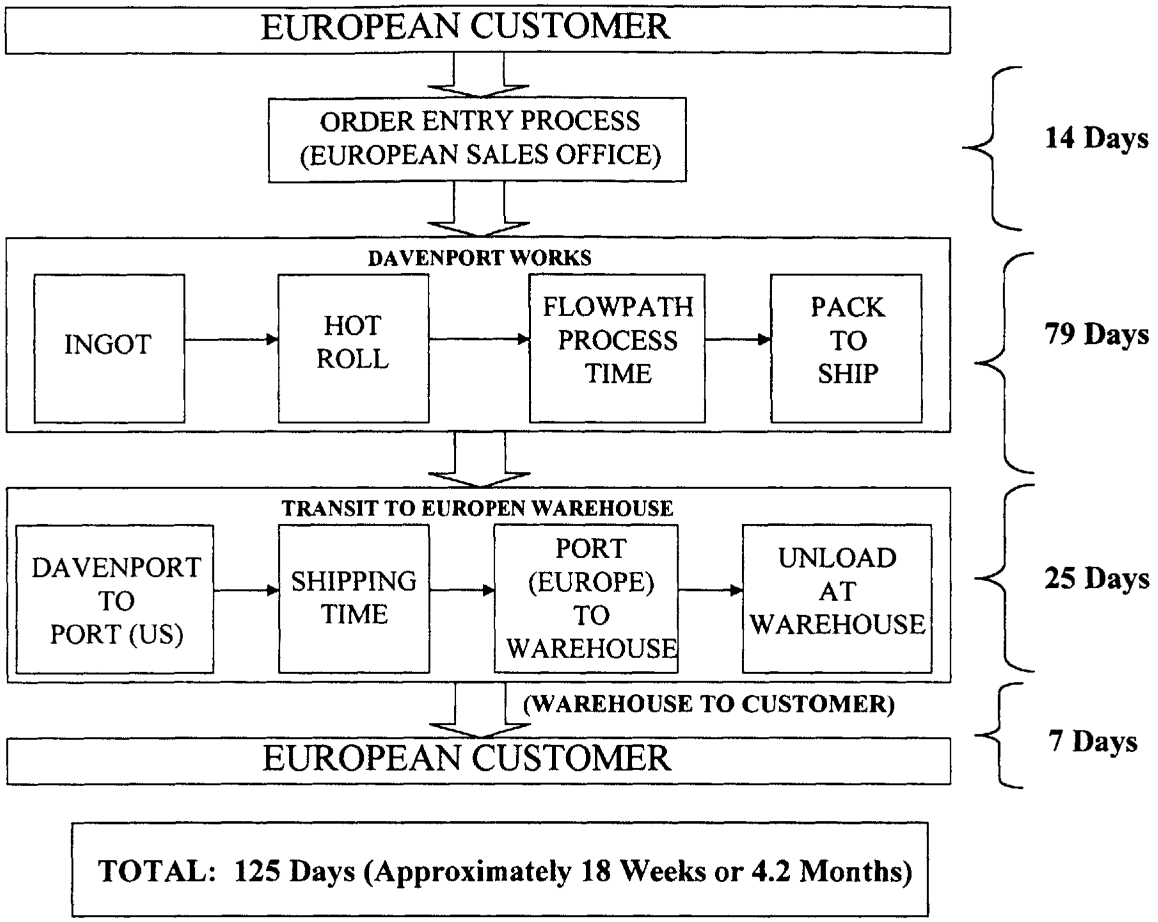
Inventory is a major investment in most manufacturing organization's supply chains but the reasons for maintaining inventory are often not understood. AMP has placed a lot of focus on developing engineered inventory levels to provide better levels of service to the customer and optimize inventories across the supply chain. Inventory is an important tool that when used correctly, can be an important countermeasure within the supply chain against obstacles that prevent the achievement of desired goals.

# CHAPTER THREE: The AMP Supply Chain

In order to conduct an analysis of the AMP supply chain, it is important to develop a thorough understanding of the different stages within the supply chain. The AMP supply chain is broad and complex. While my analysis did not explore every aspect of the AMP supply chain, I examined the critical components that were necessary to address the primary objectives of the project. My analysis focused on the operations of the European sales office; the manufacturing facility in Davenport Works; the Alcoa International Service Center (AISC) in Europe; and how they interacted with three key European customers. In particular, I was concerned with inventory management and how inventory was being utilized as a countermeasure within the supply chain to better satisfy customer needs. The scope of my analysis did not include raw material sourcing, supplier management, or the product development and engineering groups.

I broke down the AMP supply chain in accordance with the four stages of the supply chain discussed in chapter 2. The AMP supply chain is depicted in Figure 3-1. This diagram includes lead times for each individual stage in the supply chain based on the assumption that the objective is to provide the customer with approximately 95% service level. The total replenishment lead time (the time from the customer request to the time the customer receives the order) was 125 days or approximately 4.2 months. The order generation and order processing stage is centered on the European sales office although the functions associated with this stage extend outside the sales office. The manufacturing stage encompasses the Davenport Works manufacturing facility where all the products for the European customers are manufactured. The logistics stage includes both the inspect, pack and ship (IPS) group at Davenport Works and the AISC in Europe. The customer service stage extended beyond the scope of this project. While relationship management is discussed to some degree in the order generation and order processing stage, I do not discuss how AMP interacts with the customer after finished products are delivered.

**Figure 3-1: The AMP Supply Chain for European Customers.**




The analysis and documentation of the AMP supply chain was beneficial to AMP because it provided a framework for the supply chain system. This was particularly important because there was no one individual that had 100% visibility of the entire AMP supply chain. The managers at Davenport Works did not understand the specific end customer requirements because they were producing to orders generated from the sales office in Europe and these orders did not always represent exactly what the customer desired. In addition, managers at Davenport Works did not have a thorough understanding of the capabilities and functions of the AISC in Europe. Conversely, the managers in the sales office and at AISC did not have an understanding of the production processes and challenges at Davenport Works. This supply chain breakdown can be used to pass knowledge, to enhance understanding, and to provide a framework for supply chain system analysis and improvement.

## 3.1: European Sales Office

The European sales office is the home of the European sales team. They are responsible for developing and maintaining relationships with European customers. Each major customer is designated a specific sales manager and the sales manager may have a customer service representative (CSR) working with them. While the sales manager and CSR may deal with more than one customer, the customer deals with the same sales manager and CSR for every interaction. This organizational structure enhances the development of customer relationships. The customer always has a designated point of contact and continually interacts with the same individuals. The sales team (sales manager and CSR) develops an enhanced understanding of the customer and their needs because they handle all interactions for a particular customer.

The sales office is also responsible for the receipt and processing of all customer orders (European customers). They are also responsible for the operation of the AISC in Europe and in particular, the levels of inventory that are being maintained there. To facilitate this, the sales office and the AISC are both operating on the same information technology (IT) system. The new IT system is an Oracle system and was activated in July 1999. Unfortunately, during the time period when the research was conducted, the IT system in Europe and the IT system at Davenport Works were not compatible and there was no simple way to transfer data between the two systems.

### 3.1.1: Order Entry Process

Before describing the order entry process some key terms need to be defined.

- **CPN**: CPN stands for Customer Product Number. Every product produced for a customer has its own individual CPN; therefore, the CPN is both product and customer specific. The CPN is a reference point that contains all the information associated with the product for a particular customer. Even if the product information is identical for different customers, there will be two separate CPN's (one for each customer).

- **Mainframe Computer System**: The mainframe computer system is an IBM mainframe computer that is housed at the Alcoa Headquarters in Pittsburgh, PA. All orders are entered into this system.

- **Order Booking Tool (OBT)**: The OBT is a computer system that is linked to Davenport Works and determines the earliest date AMP can provide the desired product to the customer. The OBT references existing orders and manufacturing capacity to determine a promise date based on pounds and CPN. The OBT reserves capacity in the system for 48 hours like an airline reservation system. Once the reservation is actually committed to a firm order, manufacturing capacity at Davenport Works is updated.

- **Standard (STD)**: An order designated as standard or STD means that the order is associated with a stock program or a JIT program run out of the European warehouse with the customer.

- **Back-to-Back (BTB)**: An order designated as back-to-back means that the order is not associated with a stock program or a JIT program run out of the European warehouse with the customer. BTB orders are sometimes referred to as "via the European warehouse" because they just travel through the AISC before they reach the customer.

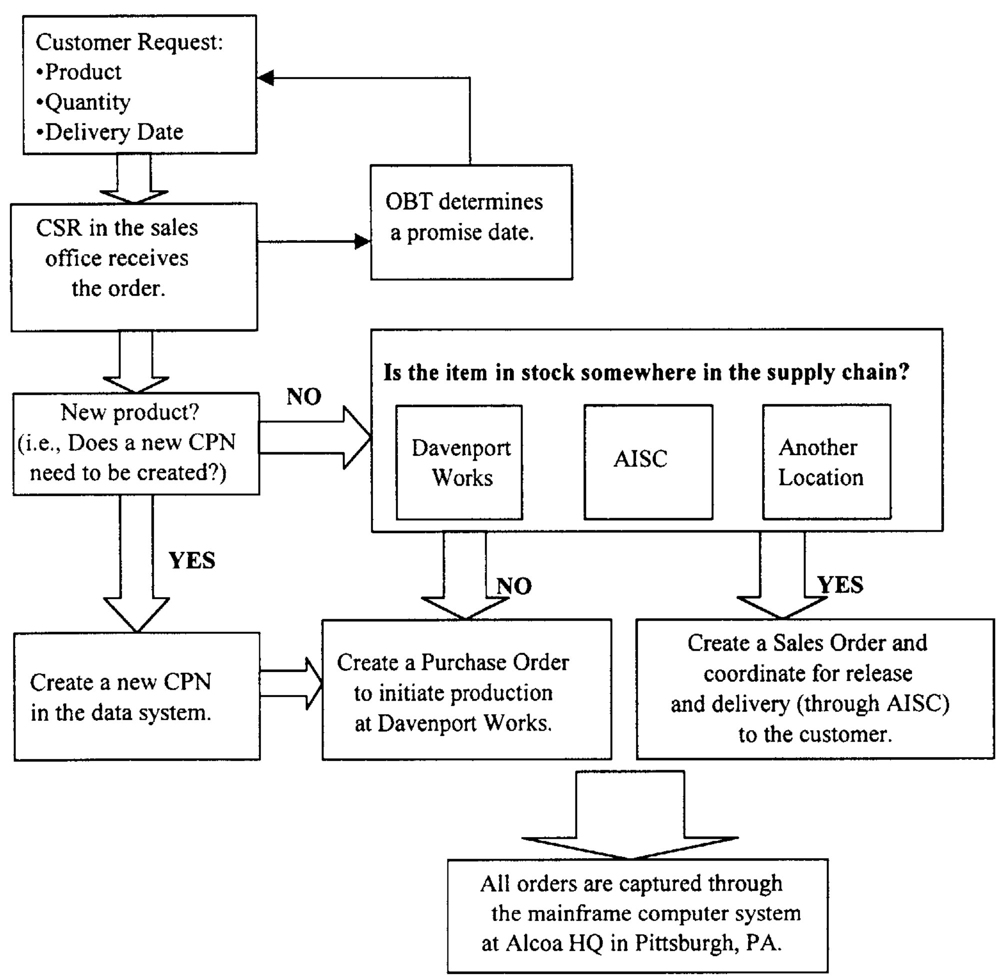
- **Purchase Order (PO)**: A purchase order represents a request to Davenport Works to produce metal for a specific customer order. Purchase orders deal with products coming into AISC; and every purchase order has a corresponding sales order when the metal gets delivered to the customer. Purchase orders are designated as either PO (STD) or PO (BTB) for internal tracking purposes within AMP.

- **Sales Order (SO)**: Sales orders are written for all products that leave the AISC to be delivered directly to the customer. Sales orders are designated either SO (STD) or SO (BTB) for internal tracking purposes within AMP.

The order entry process centers on the interaction between the designated CSR for a particular customer and that customer's designated representative assigned to AMP. The order entry process is outlined in Figure 3.1.1-1, however, I will highlight a few key points here. The CSR receives a customer order either by written document or through EDI. The order contains the specific products the customer wants, quantities (in number of pieces and weight per piece), and a desired delivery date. The first thing that the CSR does is to enter the customer request into the Order Booking Tool (OBT) to determine if the promise date given by the OBT differs from the customer's desired delivery date. If the two dates differ, the CSR will go back to the customer to see if the customer will accept the promise data given by OBT.

The CSR then determines if the order contains any new products (i.e. there is no existing CPN for the product). There are two things that can occur after this determination is made. If there is no existing CPN, the CSR initiates the process to create one. The amount of time it takes to generate a new CPN in the system varies because product specifications have to be approved, manufacturing processes to produce the product verified, and quality inspections developed. If there is an existing CPN, the CSR will search the supply chain to see if the product is already in stock. If the item is in stock, the CSR will create a SO and arrange for delivery of the product to the customer through the AISC. If the item is not in stock, the CSR will create a PO to initiate production at Davenport. Once the item arrives at the AISC, the CSR will create a SO, which causes the item to be delivered to the customer from the AISC. If an item is shipped directly to the customer without going through the AISC, neither a SO or a PO is generated because those orders are handled on a separate tracking system.

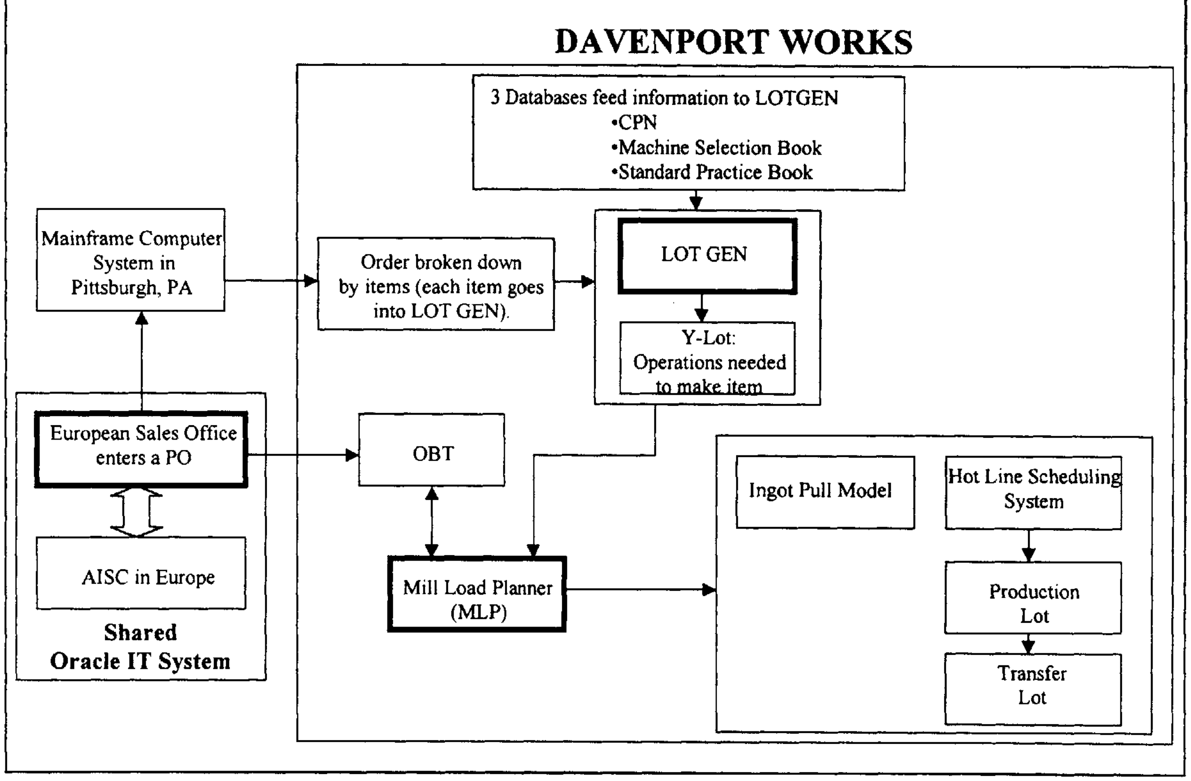
**Figure 3.1-1: The Order Entry Process at the European Sales Office.**



### 3.1.2: Information Flow

The information flow associated with a particular order is fairly complex and travels across multiple organizations and through multiple information systems in the supply chain. The information flow within the AMP supply chain is outlined in Figure 3.1-2 and provides a general overview of how information flows from the Europe to Pittsburgh and then through Davenport Works.

**Figure 3.1-2: Information Flow in the AMP Supply Chain**




The general overview of information flow within the AMP supply chain involves numerous different information systems. In Europe, the sales office and the warehouse operate under the same Oracle IT system. As a result it is easy for them to exchange information about customers, orders, inventory levels, and delivery information. Unfortunately, this IT system is only operational in Europe; and while it is possible to access the system from Davenport Works, the process is complex and extremely slow. In addition, data from Davenport Works cannot be transferred into the Oracle IT system in Europe.

The mainframe computer system in Pittsburgh serves all of Alcoa and can be considered as a hub through which all orders must pass through. In our case, the mainframe computer system breaks down each PO into separate items. The mainframe computer system in Pittsburgh downloads information into the LOT GEN computer program within Davenport Works on a continual basis (there is approximately a two-hour delay in information transfer from real-time data). LOT GEN is an old legacy system at Davenport Works that plays a crucial role in the manufacturing process. LOT GEN is basically a system of tables that references three separate databases (CPN, Machine Selection Book, and Standard Practice Book) to perform ingot selection to initiate production (although the LOT GEN selection can eventually be changed) and determine the routings of the items through the manufacturing process.

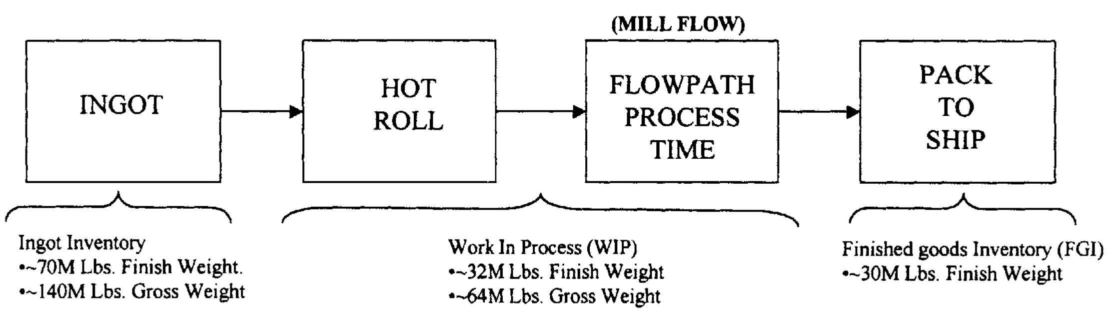
The Mill Load Planner (MLP) is a finite capacity planning tool that Davenport Works utilizes to determine when an order needs to be launched off the hot line to meet a specified delivery date. The MLP is what actually updates the capacity in the system and it is referenced by the OBT to determine promise dates. The MLP is a primary link in the overall flow of information in the manufacturing process. The MLP receives promise dates from the OBT (via the order book) and routings from LOT GEN and uses this data to feed into the production process. Ingots are produced based on an Ingot Pull Model, which references the MLP, and the hot line schedules its production through the Hot Line Scheduling System, which also references the MLP. The Hot Line Scheduling System assigns each ingot as a production lot. The production lot can be further broken down into transfer lots if one ingot is being utilized in the production of more than one order. Data on each lot is tracked and captured within a database as it moves from machine to machine through the production process.

Despite the complexity created by the numerous data systems, Davenport Works is able to capture pertinent information throughout each stage of the manufacturing process. They utilize numerous pivot tables to query information from the database to generate necessary reports for tracking and analysis. However, while the necessary information is often available in some form, pertinent information is sometimes difficult to attain and may require the assistance of an IT person.

## 3.2: Davenport Works

Davenport Works represents a major portion of the AMP supply chain and serves as the focal point of the manufacturing stage. Due to Davenport Works criticality to the supply chain it was important to develop an understanding of its processes and operations in order to analyze the entire AMP supply chain. This section provides an overview of the primary operations centers within Davenport Works.

**Figure 3.2-1: Primary Operations Centers Within Davenport Works**




It is interesting to note how much inventory Davenport Works maintains in terms of raw materials inventory (in the form of ingots), WIP inventory, and FGI (see Figure 3.2-1). Davenport Works utilizes inventory as a countermeasure and maintains significantly more inventory than any other stage within the AMP supply chain (including the European warehouse). There is enormous potential to reduce inventory levels within Davenport Works and the facility is continually exploring opportunities to do this, particularly in terms of WIP inventory.

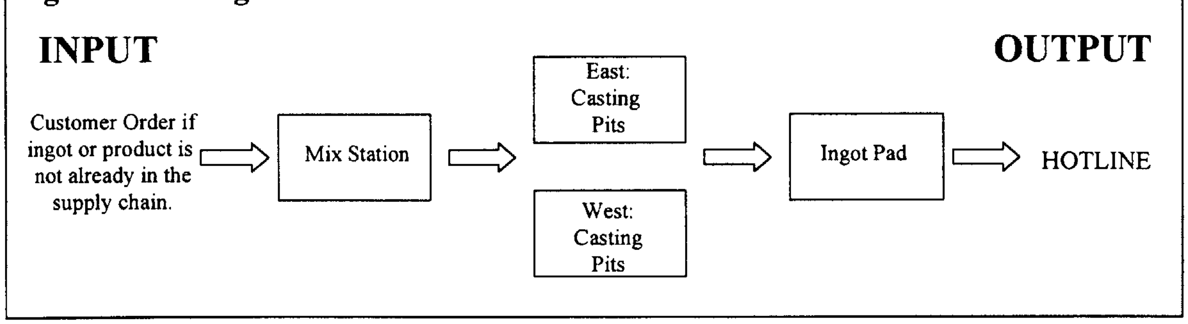
### 3.2.1: Ingot

An ingot is a cast rectangular block of metal that can be remelted or fabricated. Davenport Works produces numerous sizes of ingots. There are eleven different ingot widths in four different gauges (thickness); and ingots can range in length from 125 inches to 330 inches (generally in increments of approximately three inches). There are 185 different planned ingots for sheet products and 113 different planned ingots for plate products (there are a maximum of approximately 250 different potential ingot sizes). In addition to multiple sizes, ingots are cast in several different alloys. An alloy is a substance with metallic properties, composed of two or more chemical elements of which at least one is a metal. At Davenport Works, alloys are aluminum plus one or more other elements that are produced to have certain desirable characteristics.[31] Davenport Works utilizes seven base alloys and casts ingots for approximately 100 different combinations of the base alloys.

Ingot production is driven by the Ingot Pull Model, which is an internal scheduling tool which references several other Davenport Works computer systems (OBT, LOT GEN and the MLP). The Ingot Pull Model views weekly snapshots of demand. Demand comes from firm orders that are listed on the order book. Each order contains a promise date (derived from the OBT) and the type of ingot that should be utilized to satisfy the particular order (derived from LOT GEN). The timeline (based on the promise date) to produce the order is backed up[32] through a particular flowpath[33] to determine when the ingot should be hot rolled (the MLP does this and updates capacity within the system). The ingot schedulers/planners then subtract two weeks from when the ingot should be hot rolled to determine when the ingot needs to be cast.

The total time it takes to produce an ingot from a request (ingot lead time) is approximately three weeks. It generally takes two weeks to schedule the production of a particular ingot and one week for actual production. Figure 3.2-2 provides a general overview of the ingot production process.

**Figure 3.2-2: Ingot Production Overview**




[31] This definition of an alloy was taken from glossary section of the 1998 Alcoa Annual Report.
[32] By "backed up" I mean that the processing steps are listed from the last step to the first step and then the time to complete each step is summed. For example, if the promise date is June 28th, and it takes 27 days to complete all the processing steps within the flowpath (from Hot Roll to IPS), the designated ingot needs to be hot rolled on June 1st.
[33] A flowpath is a designated routing of a product through the manufacturing process.

Alloys are created and mixed in the mix station; and then the metal is transferred to either the East End or West End of the ingot plant for actual casting. The casting pits in the East End are more efficient at handling smaller loads while the casting pits in the West End are more efficient at handling larger loads. All ingots produced in the ingot plant are transferred to the ingot pad.

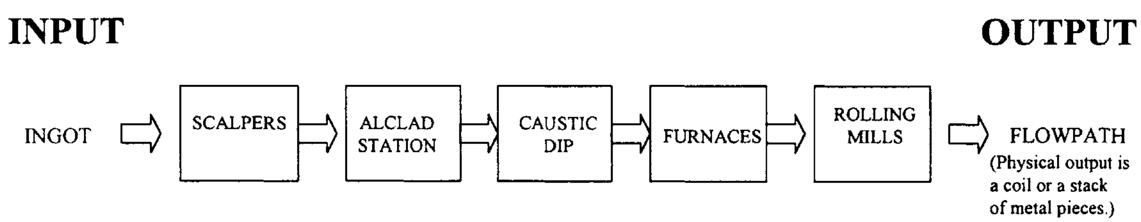
The ingot pad stores ingots in an area the size of approximately six football fields; and the time an ingot spends on the ingot pad is determined by ingot demand. The ingot pad is necessary based on the current casting practices because ingots are not cast on an individual basis. Depending on the size of the ingot and the type of alloy, anywhere from 4-7 ingots are cast per drop. Therefore, due to economies of scale in ingot production, each drop may (and probably does) produce excess ingots that remain on the ingot pad for a period of time. Future ingot demand can be satisfied from these excess ingots that have already been cast and are sitting on the ingot pad. Furthermore, in an effort to shorten the time it takes to get the product to the customer, a planner may substitute an ingot already sitting on the ingot pad rather than cast the particular ingot designated by LOT GEN for a particular order. The practice of ingot substitution and satisfying ingot demand from stock requires a detailed information tracking system to ensure the proper ingot is assigned to the proper order.

### 3.2.2: Hot Roll

The first steps in the fabricating process of an ingot occur on the hot line. The primary purpose of the hot line is to flatten the ingot to the desired gauge by sending it through metal rollers while the ingot is heated. An ingot is taken from the ingot pad and goes through scalpers in a scalping station. The scalpers cut impurities in the metal off the ingot. The scalped ingot then moves through the alclad station. In the alclad station pure aluminum (i.e., alclad) may be applied to one or both sides of the scalped ingot.[34] The alclad provides a protective coat on the outside of the metal to reduce the effects of corrosion. After the metal moves through the alclad station, the ingot is dipped in a caustic solution that cleans the metal. After the metal goes through the caustic dip it goes into furnaces where the metal is heated before it goes through the rolling mills. There are several rolling mills in the hot line and they are referred to by the maximum width of metal that can be rolled through the mill.[35] As the metal rolls through the mill it is flattened and lengthened (it does not widen unless broadening passes are planned). After the ingot has been flattened to the desired gauge it is either rolled into a coil or cut into a stack of metal pieces where it then moves onto its designated flowpath.

The lead time associated with an ingot moving through the hot line (hot roll lead time) is approximately two weeks. The rule of thumb used at Davenport Works is that it takes approximately two weeks to schedule a particular ingot for the hot line and one day to actually perform all the processing steps. A general overview of the hot roll processing on the hot line is shown in Figure 3.2-3.

**Figure 3.2-3: Overview of Hot Roll Processing on the Hot Line**



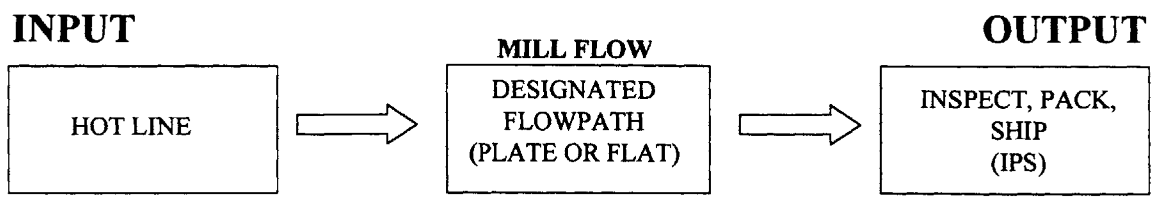

### 3.2.3: Flowpath Process Time (Mill Flow)

After the metal leaves the hot line it continues through the rest of the manufacturing process on a designated flowpath. Since Davenport produces over 11,000 different product specifications, they have developed several different flowpaths to serve as tools to facilitate the tracking and processing of certain groups of products. A flowpath can simply be thought of as a particular routing through various production centers from the end of the hot line stage to the beginning of the inspect, pack and ship (IPS) stage (see Figure 3.2-4).

[34] Not all items have alclad applied and hence go through the rest of the production process "bare".

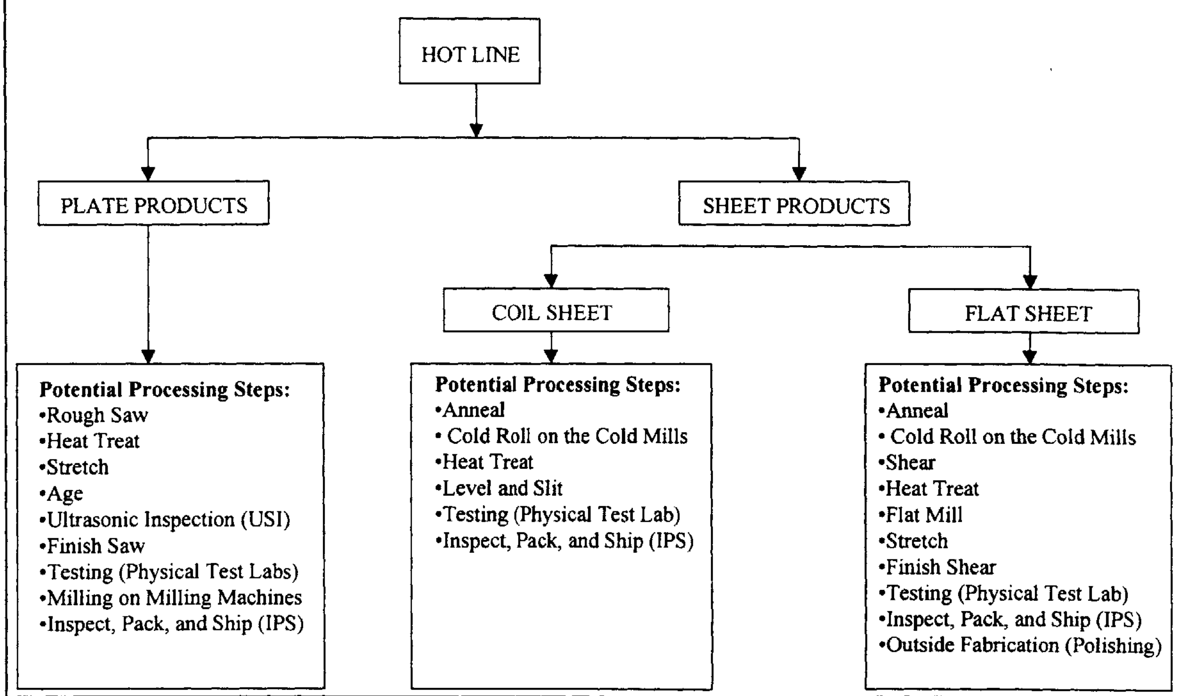
[35] A reversing mills is a mill where the metal is rolled back and forth through the mill to achieve the desired gauge reduction. A continuous mill is where the metal rolls through continuously in one direction through as many as five different rolls to achieve the desired gauge reduction.

**Figure 3.2-4: Where Flowpaths Fit in the Manufacturing Stage**




At the time of the research, there were six major grouping of flowpaths, thirty primary flowpaths (8 for plate, 13 for flat sheet, and 9 for coil sheet), and several sub-flowpaths within the primary flowpaths. Depending on the particular product being manufactured and the flowpath the product is on, there are several different processing steps that the product may go through. Figure 3.2-5 gives a listing of the various manufacturing-processing steps a product may go through (each product does not go through every processing step and the order of the steps may vary).

**Figure 3.2-5: Manufacturing Processing Steps**




Here are some brief definitions for some of the processing steps:

**Heat Treat**: In heat treating the metal is heated to very high temperatures to achieve certain properties in the metal as well as strengthen it.

**Stretch**: After heat treating the metal, the metal is placed in two hydraulic clamps and stretched to achieve certain properties in the metal as well as improve flatness.

**Age**: Aging is another form of heating the metal and is done to strengthen the metal.

**Ultrasonic Inspection (USI)**: After the majority of the processing has been completed, certain products are dipped into a tank of water to be ultrasonically inspected. This process is done to identify any defects or inclusions in the metal piece. If defects are found the metal is scrapped.

**Milling**: Milling is done to smooth the surface of the metal and can also be done to reduce gauge by very small amounts.

**Anneal**: Annealing is another form of heating the metal and is done to soften the metal for further processing.

**Cold Roll**: Cold rolling is done on a cold mill which is a piece of equipment that allows aluminum to be rolled through a pair of rollers under pressure to help form the aluminum into desired sheets. It is given the term "cold" rolling because the incoming metal is usually at room temperature.

The general rule of thumb at Davenport Works is to allocate approximately twenty-one days to manufacture a product once the item enters a particular flowpath. Due to the criticality of the flowpath processing within the manufacturing stage I analyzed the mill flow lead time data that is captured within the Davenport Works information system to better determine the length of time a product may spend on a particular flowpath. This mill flow lead time is critical because not only does it represent the longest lead time in the entire supply chain, but more importantly, the processing steps performed on a particular flowpath are the steps that will have to be repeated if there is a quality problem or if the product needs to be re-manufactured for some reason.

Davenport Works tracks the amount of time it takes a lot to move from the end of the hot line to when it is packed at IPS.[36] I collected data for each primary flowpath for plate and flat sheet products. I created a distribution of flow times for each flowpath, eliminated outliers, and tested each distribution for normality utilizing normal probability plots (I tested for normality so that I could use ($\mu + 2\sigma$) for approximately 95% confidence). If the normality assumption were weak for a particular data set I would transform the data (utilizing square root or LOG) and create a normal probability plot again. This was sufficient for the majority of flowpaths but if the normality assumption was still weak, I utilized only percentiles. The results are shown in Figure 3.2-6.

**Figure 3.2-6: Mill Flow Lead Time Data Analysis (By Flowpath)**

| FLOWPATH | 95% Confidence | Raw Data 75th Percentile | Raw Data 90th Percentile |
|---|---|---|---|
| PH1 | 54* | 34 | 46 |
| **PH2** | **41*** | **26** | **35** |
| PH3 | 60* | 33 | 47 |
| PH4 | 43 | 24 | 32 |
| PH5 | 50* | 37 | 44 |
| PH6 | 101 | 47 | 55 |
| PH7 | 64 | 33 | 43 |
| PN5 | 48 | 25 | 31 |
| | | | |
| **FT1** | **77** | **38** | **49** |
| FT2 | 55 | 32 | 40 |
| **FT3** | **84*** | **57** | **71** |
| FT4 | 32 | 15 | 21 |
| FT5 | 55 | 34 | 41 |
| FT6 | 60* | 34 | 44 |
| | | | |
| **FV1** | **60** | **33** | **46** |
| FV2 | 51 | 25 | 33 |
| FV3 | 44 | 23 | 29 |
| **FV4** | **56*** | **44** | **50** |
| **FV5** | **74** | **39** | **50** |
| **FV6** | **81** | **47** | **59** |
| FV7 | 58 | 34 | 46 |

Numbers are represented in Days.
PH2, FT1, FT3, FV1, FV4, FV5, and FV6 are the primary flowpaths we are concerned with.
* Used 95th percentile of raw data rather than ($\mu + 2\sigma$) of transformed data if normality assumption was weak.

The mill flow lead time data analysis showed that the lead times were uncharacteristically long when compared to the lead times they utilize for planning

[36] A lot is a designation given to a particular group of metal. The information on the mill flow lead times are queried from the system database and tabulated in an Excel pivot table (S:\Departmental\Supply Chain Management\Fast Flow\42 Day Team\[Flow Time Pivot (Fixed).xls]Flow Pivot).

purposes. A possible reason for this could be that the data took into account all lots (with the exception of outliers[37] which were removed from the data set) run on a particular flowpath, and the data points did not distinguish whether the hot roll date for the lot was early, late, or on time. Extremely long flow times may be contained in the data set for lots that are hot rolled early and then spend a lot of queue time within the flowpath. In addition, extremely short flow times may be contained in the data set for lots that are hot rolled late and then have to be expedited through the flowpath. These data points could skew the results.

In general, the mill flow lead times based on the data analysis are significantly greater than the mill flow lead times that are quoted by people within AMP (both production, and marketing and sales). The analysis may have inflated the mill flow lead times to some extent (even though outliers were eliminated), but the differences seem too significant to ignore. If delivery performance were in the 90% range I would tend to ignore the data and go with the popular opinion. However, this is not the case and further analysis should be conducted and may reveal that actual mill flow lead times are greater than the perceived mill flow lead times.

Regardless of the specific mill flow lead time, the data does show that mill flow lead times are going to vary for each flowpath. This makes it difficult to quote a "general" lead time for a particular customer (i.e., submit all orders four months in advance) for all products. Mill flow lead time is actually flowpath (or more specifically product specific) specific and should be quoted to the customer as such. If one mill flow lead time must be quoted, then trade-offs between delivery performance and holding inventory must be balanced against one another. Ideally, AMP would like to quote the customer a product specific lead time as opposed to a single lead time (which is often the case in customer contracts) that must be applied to all products.

---

[37] An outlier was defined as an observation with a z-score (z-score = $(x - \mu) / \sigma$) less than three in absolute value.

### 3.2.4: Inspect, Pack, and Ship (IPS)

The inspect, pack and ship (IPS) station within Davenport Works takes finished products from each of the flowpaths, packages the metal and ships the packages via rail or truck to the customer or to another node in the distribution network. Product inspections are completed before the metal reaches IPS and IPS does not do any inspection of the metal.

The general rule of thumb is that metal stays within IPS for approximately nine days (IPS lead time). The most significant portion of time the metals spends in IPS is due to scheduling issues. Firstly, IPS tries to achieve economies of scale in transportation by not shipping until full truckloads and full rail cars can be assembled. Secondly, all international shipments must be made in containers; and IPS tries to assemble full containerloads before shipment. Thirdly, for some routes deliveries are not done on a daily basis (specifically for rail); and as a result product may have to wait in IPS due to infrequent deliveries. In addition to the scheduling issues, IPS spends time locating correct packages (which can be significant in an area with 32 million pounds of FGI), consolidating customer orders, and loading trucks, rail cars and containers. It generally takes three days to load a typical rail car, one day to load a full container, and a few hours to load a truck.

## 3.3: Alcoa International Service Center (AISC) in Europe

The Alcoa International Service Center (AISC) is located in Europe and contains a large warehouse that maintains inventory for AMP's European customers. Ninety eight percent of all metal for continental Europe (excluding the United Kingdom) flows through the AISC and the European warehouse receives approximately 35-40 million pounds of metal per year from Davenport Works. The lead time associated with the logistics of flowing metal through the AISC is approximately 32 days (AISC lead time). Seven days are allotted for the containers to be transported from Davenport Works to a US port, to be processed within the port (includes queue time), and to be loaded onto a ship ready for shipment to Europe. Ten days are allotted for the actual shipping time across the Atlantic. Seven days are allotted for the containers to be off-loaded from the ship, processed in the European port (includes queue time), and transported to the warehouse. One day is allotted to unloading the trucks at the warehouse. Seven days were allotted to receive instructions to deliver the items, to locate the items in the warehouse, to load the truck, and to transport the product from the warehouse to the customer.

The warehousing procedures at the European warehouse are fairly straightforward. The primary goal of AISC is to ship to the customer on time. If items are produced early at Davenport, they are stored at the European warehouse and then shipped to arrive on the customer's desired delivery date. If items are shipped late from Davenport, the European warehouse ships the items to the customer when they arrive, but the warehouse's delivery performance is not negatively impacted. The majority of items are organized in piles of approximately the same size within designated areas on the floor, which are bar coded and outlined in yellow tape on the floor (there are also a few rows of vertically stacked shelves). When an item is dropped off within a particular area, an individual scans the bar code on the floor, which allows the information system to record the item's location in the warehouse. This system facilitates the easy retrieval of items for customer deliveries.

The processing capabilities at AISC are significant. Although AISC performs some processing on certain items as well as operating both JIT and "cut-to-size" programs with certain customers (these programs will be discussed in chapter four), there may be opportunities to increase the utilization of the AISC's capabilities. More extensive utilization of AISC's capabilities could provide more supply chain flexibility and hence increase the level of service AMP can provide to the customer while at the same time increasing the efficiency of the entire AMP supply chain for European customers.

The warehouse measures over 10,000 square meters and has one overhead crane that provides 90% coverage of the facility. The AISC also developed and utilizes an "Optimizer Program", which is a computer program for their two CNC saws. The "Optimizer Program" is utilized in their Cut-to size program and allows them to cut multiple items out of a stock piece with the objective of minimizing scrap. The AISC also has significant capabilities in their equipment:

| | |
|---|---|
| • Two CNC Saws | • MAX Gauge: 5.5 inches (139.7mm)<br>• MAX Length: 165 inches (4200mm)<br>• MAX Width: 165 inches (4200mm)<br>• Saws only cut straight therefore only straight shapes.<br>• Saws currently run 2 shifts per day, 5 days per week.<br>• Takes two months to train a new crew.<br>• Currently would not consider sawing sheet products because of quality (tolerance) problems. |
| • One Shear | • MAX Gauge: 0.157 inches (4mm)<br>• MAX Length: 236 inches (6000mm)<br>• MAX Width: 236 inches (6000mm)<br>• Currently testing the maximum gauge tolerances. |
| • CNC Milling and Drilling Capabilities | • Use to drill transportation holes. |

## 3.4: Chapter Summary

The AMP supply chain is globally extensive, complex and full of numerous supply chain challenges. Before supply chain problems can be addressed, the entire supply chain system must be laid out and understood. This chapter provides a layout of the entire AMP supply chain to help develop that understanding. If knowledge about the entire supply chain system could be taught and shared amongst all the different stages in the supply chain root cause problems could be better identified and solutions that optimize the entire supply chain (rather than a localized segment of the supply chain) can be implemented.

# CHAPTER FOUR: Customer Analysis and Product Breakdown

A thorough supply chain analysis must include a breakdown of both the key customers and products. This chapter describes the customer programs for the three largest customers for AMP in Europe and examines the product mix for these three customers. In addition, this chapter addresses the cost considerations associated with the scrap vs. hold in inventory issue on certain classes of products.

## 4.1: The "Big Three" Customers

As of July 1999 AMP was serving approximately forty-three different customers in Europe through the AISC. To support these customers, FGI (both at the European warehouse and in transit) totaled 9.4 million pounds valued at approximately $25 million. The data analysis revealed that three customers accounted for over 77% of the volume and 73% of the value for all the European FGI. Those three customers were "Customer B" (1.9 million pounds valued at approximately $4 million), "Customer A" (1.5 million pounds valued at approximately $4.8 million), and "Customer C" (3.9 million pounds valued at approximately $9.5 million). In addition to representing the majority of the business for AMP in Europe, these three customers operate under a variety of different customer programs with AMP that result in significant supply chain management challenges.

### 4.1.1: "Customer A"

**BACKGROUND:** "Customer A", who used to be called Air Italia, is a manufacturing subcontractor for the aerospace industry and is located in Italy. They work with the major aircraft manufacturers and are involved in the production of the following aircraft: MD-11; MD-80; Boeing-767; Boeing-717; A320; A321; FALCON; TORNADO; G222; ATR; and various other items.

**CUSTOMER PROGRAM SPECIFICS:** "Customer A" and Alcoa are operating under a contract that covers the period from January 1, 1997 through December 31, 2000.

Alcoa is the 100% supplier for "Customer A" and provides them with various plate and sheet products. The contract is detailed, complex, and contains numerous requirements for both parties. Due to the complexity and language of the contract, requirements on both sides are difficult to determine and often misunderstood.

The contract outlines several major requirements for AMP that impacts the supply chain. Firstly, AMP is required to maintain a 25% safety stock (of annual demand) for all items "Customer A" orders. The composition of the safety stock is determined and adjusted every three months. The stock is to be maintained at the AISC (or a location of Alcoa's choosing) and evaluated monthly. Alcoa also must provide a written report to "Customer A" every month on the composition of the safety stock. Furthermore, "Customer A" can request all or a portion of the safety stock at any time; and delivery must be made within ten days of the request. Secondly, Alcoa must provide written Certified Inspection Reports for all metal shipped to "Customer A". Thirdly, Alcoa operates a JIT program with "Customer A"; and "Customer A" pays a premium on orders submitted for JIT delivery. The program allows for reduced delivery times of six months from the order submission date. "Customer A" can request deliveries on these orders any time after six months and AMP must deliver the metal within one week of request. Fourthly, the contract allows "Customer A" to order in quantities less than the mill minimum order quantities for Davenport Works without penalty so long as the annual quantity ordered is greater than the mill minimum order quantity. Finally, there are several stipulations in the contract concerning lead times (ranging from 6-9 months), packaging, and various penalties (lateness, quantity tolerances, and quality).

The only major contract requirement for "Customer A" that impacts the supply chain concerns forecasting and ordering policy. "Customer A" is required to provide Alcoa with firm orders six months out and a rolling six-month forecast that is updated monthly. For example, on 1 January "Customer A" will be submitting firm orders for 1 July and a rolling forecast covering the time period 2 July through 1 January of the next year.

**SUPPLY CHAIN ISSUES:** "Customer A" poses several supply chain issues for AMP.

- The first issue revolves around the contract itself and the adherence to the guidelines established in the contract. The contract was put together solely in the European sales office without input from the Sales and Marketing Groups at Davenport Works. The contract failed to consider the capabilities of the supply chain and as a result, several of the requirements that AMP is required to provide put a strain on the AMP supply chain. This is particularly relevant with the safety stock requirements and the allowance of "Customer A" to submit orders that are less than minimum order quantities established by Davenport Works. In addition, neither party adheres to the guidelines established in the contract and neither party imposes penalties on the other for contract violations. This actually has been working in AMP's favor since they have not been maintaining the correct levels of safety stock nor providing the required safety stock reports to "Customer A". Although "Customer A" has not been providing AMP with rolling forecasts, this has not been a major issue since they do submit firm orders six months out and AMP builds to order. Regardless of the effects on both parties, contracts are written for a reason; and if the guidelines of the contract are going to be totally disregarded then it is difficult to structure your supply chain to satisfy customer needs.

- The second issue revolves around order quantities. Because Davenport Works tries to achieve economies of scale by producing in increments of the recovery[38] of an ingot (i.e., utilizing a complete ingot for each individual order), they have established minimum order quantities for European customers. Ironically the minimum order quantity has nothing to do with the manufacturing process. The minimum order quantity of approximately 4000 pounds was established by the Marketing Department; and that number was chosen because that is what other European suppliers were offering their customers. Despite the establishment of minimum order quantities to Davenport Works, "Customer A" is allowed to place orders below the minimum order quantity without being penalized so long as the annual demand is greater than the minimum order quantity for a particular product. "Customer A"'s

[38] Recovery is an internal performance metric used by Davenport Works. Recovery = (Pack Weight) / (Gross Weight). Pack Weight is the amount of metal packed from a particular ingot. Gross Weight is the weight of the ingot after it has been scalped. The objective is to maximize the recovery number.

order quantities (sometimes only a few hundred pounds) causes problems throughout the AMP supply chain because it is not designed to handle such small orders. Tension builds between the sales office in Europe who enters the order and Davenport Works who must process them. In particular, it is difficult to get agreement on who should be responsible for the extra metal produced (overage) and where it should be stored (Davenport or the European warehouse).

- A third issue is the extreme demand variability associated with "Customer A". "Customer A" operates under an MRP system and maintains their own stock of parts, which they resupply with parts from the European warehouse (which are produced at Davenport Works). They place firm orders six months out, but there is no correlation between the orders they place and the build rates of the airplanes they produce. In addition, their order patterns are variable in terms of both timing and quantity. Fortunately, they provide firm order six months out and that provides significant time for the supply chain to process the orders, manufacture the parts, and deliver to the customer. However, if that lead time is reduced or AMP has to deviate from their make to order practice with this customer, there could be significant delivery performance issues.

"Customer A" represents a customer that imposes significant challenges on the AMP supply chain. They order in small quantities (less than the mill minimum), demand is extremely variable and they operate under a JIT system with the European warehouse. On the positive side, Alcoa is the 100% supplier for "Customer A" and AMP has negotiated very good prices with this customer. However, the contract with "Customer A" expires at the end of 2000; and negotiations are underway. AMP must examine the capabilities of their supply chain and search for ways to better satisfy the customers need for smaller quantities because that requirement will not likely change. Inventory management will be critical to successful operation with "Customer A".

The MD-80 and MD-11 are no longer being produced so there is some concern with how this will impact "Customer A"'s total metal requirements from Europe.

### 4.1.2: "Customer B"

**BACKGROUND:** "Customer B" is a French aerospace manufacturer and is a major player in the Aerospace market. Like the majority of European companies, "Customer B" mandates multiple suppliers; and as a result Alcoa has approximately 35% of "Customer B"'s business with the majority of the balance going to Pechiney (a European based aluminum company).

Delivery performance is of primary importance to "Customer B"; and AMPs delivery performance for "Customer B" from the European warehouse has been well below desired levels. Despite the poor delivery performance, at the time of the research there were no stocks of FGI being maintained in the European warehouse for "Customer B" to compensate for Davenport's delivery inconsistencies. In light of the traditionally poor delivery performance, rather than establishing designated FGI (safety stock) for "Customer B" in the European warehouse, the sales manager in Europe began to subtract an additional two to four weeks (depending on the particular product) from the desired delivery dates when placing orders to Davenport in an effort to increase on-time deliveries. The 2-4 week lead time buffer has more or less prevented any significant delivery performance problems. However, on-time deliveries are extremely important to "Customer B" and will become more important once the new customer program (called the "Green Loop" Program) with AMP is initiated.

**CUSTOMER PROGRAM SPECIFICS:** The majority of emphasis on conducting business with "Customer B" is focused on the development and execution of the Green Loop Program. This customer program emphasizes 100% service levels coupled with accurate forecasting. The Green Loop Program stipulates that AMP will provide 100% service level to "Customer B" for designated products. Despite the high service level, according to the contract AMP is not required to maintain certain levels of FGI for "Customer B" in the European warehouse. "Customer B" is not going to concern themselves with how AMP provides the 100% service level; they just require that they do. To facilitate this, "Customer B" will provide AMP with a 12-month rolling forecast that is updated monthly; and all items within the forecast that are within four months of their due date are considered firm orders. There is optimism that "Customer B" will provide accurate forecasting due to the fact that over the past few years "Customer B" has undergone a major SAP implementation and this has greatly improved their planning capabilities and forecasting accuracy.

The objectives of the program are extremely aggressive and present significant supply chain challenges. In fact, "Customer B" attempted to run this type of program with another supplier three years ago but was unsuccessful. Therefore, the program will initially involve only 5 pilot items. If the program runs smoothly, there are plans to extend the program to "Customer B"'s entire product mix.

**SUPPLY CHAIN ISSUES:** This program poses several significant supply chain challenges for AMP.

- First, based on current performance, the AMP supply chain is not designed to provide 100% service levels; and the situation is going to get worse because "Customer B" will be reducing the amount of inventory they maintain as a buffer against AMP. In light of expectations of 100% delivery performance, "Customer B" is currently running their stocks down. In the past, when AMP was late with a delivery, "Customer B" could draw metal from their own inventories to prevent any disruptions to their production lines. However, once they run their stocks down, late deliveries will cause much greater difficulties because they will not have any stock of their own to use as a buffer against AMPs problems. Therefore, AMP will have to maintain large amounts of inventory to ensure 100% service levels.

- Second, the administrative procedures are not in place to expand this program to a large scale. Currently the program is being managed manually with Excel spreadsheets for the five pilot items. Since the customer has over 150 different items it would be administratively impossible to run Green Loop across their entire product mix via Excel spreadsheets. To address this issue, AMP is working with "Customer B" to develop a system whereby orders are submitted electronically (via EDI) to the European warehouse. This will enable order releases out of the European warehouse to be generated without somebody physically entering orders in the European sales office. They also need to incorporate "Customer B"'s forecast into AMP's Oracle IT system to make this work.

### 4.1.3: "Customer C"

**BACKGROUND:** "Customer C" is a German based manufacturer and represents AMP's largest customer in Europe. AMP services three different locations for "Customer C": "Location 1"; "Location 2"; and "Location 3". Each location operates independently in their dealings with AMP. "Location 1" deals with only sheet products and "Location 2" only deals with plate products. "Location 3" only deals with plate products as well, but they operate under a "cut-to-size" program with the AISC.

**CUSTOMER PROGRAM SPECIFICS:** The customer program between "Customer C" and Alcoa is structured around a series of different contracts (one supply contract, two warehouse contracts, and a frame contract for each product). "Customer C" and Alcoa operate under the umbrella of a large supply contract (the "Grand contract) that states an annual volume by product for all "Customer C" business (i.e., "Location 1", "Location 2" and "Location 3" combined). The current supply contract covers the time period from 1998 through 2001. In addition to the supply contract, there are also warehouse contracts (one for "Location 1" and "Location 2", and a separate one for "Location 3") which contain guidelines concerning metal for "Customer C" being maintained in the European warehouse. The warehouse contract for "Location 1" and "Location 2" outlines the costs associated with warehousing and safety stocks. The warehouse contract for "Location 3" covers the prices for warehousing, sawing, milling and drilling as well as details for delivery times and safety stocks. In addition to the supply contract and the warehouse contracts, "Location 1" and "Location 2" also provide the European sales office with frame contracts. A frame contract is product specific and contains the total annual volume for a given year, but no delivery dates are specified in the contract. While the contracts provide the framework under which the two companies conduct business, the Lieferplan is the primary planning tool for AMP. The Lieferplan is essentially a 12-month rolling forecast that contains specific delivery dates with specific weights and number of pieces per individual shipment. Throughout the year, "Customer C" request metal through call-offs (which must be filled within one week) based on the Lieferplan.

Alcoa is not required to maintain any inventory stocks for the items outlined in the contract; however, Alcoa is required to provide a 100% service level. "Customer C" does not dictate how Alcoa should manage their inventories, they just require 100% delivery performance. In actual practice, all locations expect Alcoa to maintain 1-2 months of inventory in the European warehouse (AMP increases this as they see fit based on intuition) and they pay for the warehouse costs to do this. This is understandable because "Customer C" does not maintain their own stocks of inventory, therefore, they are totally dependent on Alcoa providing the right metal in the right quantities at the right time to ensure their production lines continue to run. To ensure 100% service level, the CSR for "Customer C" in the European sales office is continually checking the OBT to determine accurate estimates for replenishment lead times (plate products are grouped by alloy and sheet products are grouped by dimensions). These estimates are utilized when determining when to place orders into Davenport Works. In addition, the CSR utilizes lead time padding when placing orders to Davenport Works as a buffer against late shipment to the European warehouse. Based on this system, AMP has been able to operate with few problems in dealing with all three locations.

Accurate forecasts are essential in dealing with "Customer C". "Location 1" provides the European sales office with a twelve-month rolling forecast that they update every quarter. "Location 2" is not as detailed as "Location 1". "Location 2" provides a 12-month forecast for the entire year (usually in October of the preceding year) and updates it quarterly. The updates do not extend beyond the current year of the 12-month plan. "Location 3" provides a 12-month forecast and updates it every four weeks for the following 12-months. In general, "Customer C" rarely changes their forecast within a six-month window. This combined with the updates facilitates accurate planning within AMP.

The cut-to-size program with "Location 3" capitalizes on some of the capabilities within the AISC and could serve as a model for how this type of program can be utilized for other customers. All products for "Location 3" are cut from standard size stock pieces produced in Davenport and kept in the European warehouse. The stock pieces are kept for different alloy, temper, alclad, and gauge combinations. To replenish the stock pieces, the CSR in the European sales office takes the forecast provided by "Location 3" and calculates the total square meter requirements (by alloy, temper, alclad, and gauge) and determines necessary stocking levels accordingly. Orders are placed to Davenport to ensure the calculated stocking levels are maintained. The customer submits call-offs (approximately 200 per week) directly to the European warehouse via EDI. The European warehouse then inputs the orders into their optimizer program and the end products are cut from stock pieces. While there is a trade-off made with increased recovery, this system greatly increases the flexibility AMP has in dealing with the customer.

**SUPPLY CHAIN ISSUES:** The customer program with "Customer C" is running very smoothly but major supply chain challenges still exist.

- Firstly, it is a major supply chain challenge any time you are required to provide 100% service levels to a customer. This is particularly crucial to "Customer C" because they are such a large customer and they are totally reliant on Alcoa for certain products. The volume of products and the large number of different product specifications make it difficult to manage from an inventory perspective. Currently the utilization of lead time buffers has been sufficient to avoid any major problems. However, as the customer demands increasingly shorter and shorter lead times, inventory management problems will surface and will have to be addressed.

- Secondly, the utilization of specific contracts and forecasts are extremely detailed and vary based on the particular customer location. This situation requires an excellent administrative system to ensure the smooth flow of information. As each organization strives to operate more efficiently the strain on ensuring the smooth flow of information across the supply chain will become increasingly difficult. In addition, if the trend is to move towards a more automated system in order processing with the customer (i.e., EDI) this new system will have to be developed and proper procedures established.

- Thirdly, "Customer C" is currently the only customer that operates under a cut-to-size program with the European warehouse. Due to the significant capabilities of the

AISC and the fact that the capacity is underutilized, it is only a matter of time before cut-to-size type programs are run with additional customers. As more strain is put on the AISC (both in terms of increased processing as well as increased administrative requirements) there is potential for service levels to drop. AISC needs to ensure that the proper systems are in place to ensure that existing customers do not suffer as the range of services they provide expands.

## 4.2: Product Breakdown

I focused my efforts on two primary areas when analyzing the product mix for the Big Three. Firstly, I wanted to capture the magnitude and variety of the product mix and to explore the extent of any overlap in specific products between customers. Secondly, I wanted to develop a demand history by product for each of the key customers and examine the variability of demand. This section will discuss the magnitude and variety of the product mix and the demand variability will be discussed in Chapter Five.

To generate a sense of demand by customer for each product, I collected all the orders (purchase orders and sales orders) that had been entered into the system by a CSR in the European sales office for 1999 as of 23 September 1999. Therefore, the data set I used for customer demand contained orders with due dates from 1 January 1999 through 31 December 1999. However, based on the order patterns for each of the Big Three customers, the magnitude of demand after September 1999 varied (i.e., some customers entered orders into the system early while others entered orders in a time frame closer to when they would actually need the products). To avoid the impact of the timing of orders submitted to AMP by the customer, when analyzing the demand variability I only utilized demand data with delivery dates from January 1999 through June 1999 because that time period represented demand that already occurred. However, when analyzing the magnitude and variety of the product mix, I utilized all the products contained in the orders for the entire data set (i.e., all orders entered in the European sales office as of 23 September 1999) in order to capture as many product specifications as possible.

### 4.2.1: Distribution of Products Across the "Big Three"

There are inconsistencies throughout AMP on how specific products are characterized and reported. Products were reported by CPN; part numbers; and a combination of Product Number, Product Code, Alloy, Temper, Alclad, Gauge, Width, and Length (Unfortunately all eight were rarely included in a single database report.). To gain a detailed description of a product, I differentiated the products by the following eight characteristics:

1. **Product Number (PN):** The product number designates the type of product. (12 is a Plate product and 14 is a Sheet product). The product number is based on the gauge of the metal.

2. **Product Code (PC):** A product code is assigned to a product to describe certain attributes associated with the product. The product code can incorporate what type of product specifications (quality, testing, and marking) are associated with the product.

3. **Alloy:** An alloy is a substance with metallic properties, composed of two or more chemical elements of which at least one is a metal. At Davenport Works, alloys are aluminum plus one or more other elements that are produced to have certain desirable characteristics. Alloy is determined at the time the ingot is cast.

4. **Temper:** Temper designates certain properties that the customer desires in the metal and is achieved during the manufacturing process. Temper is achieved at various stages within the flowpath.

5. **Alclad:** Alclad is a layer of pure aluminum that is applied to the surface of the metal to increase protection against corrosion (aluminum oxidizes and can heal itself, for small scratches and grooves). Alclad is applied on two sides (AL2S), one side (AL1S) or not at all (BARE).

6. **Gauge:** The thickness of the metal piece. The gauge is generally determined after the metal goes through the hot line and through cold rolling operations(although some gauge reduction can be achieved through milling).

7. **Width:** The width of the metal piece. Width is usually determined at the end of the production process on the finish saws and shears.

8. **Length:** The length of the metal piece. Length is usually determined at the end of the production process on the finish saws and shears.

The breakdown of products for the Big Three customers is shown in Figure 4.2-1. The breakdown of the products shows us several things.

- The product mix for the Big Three is much more extensive than initially anticipated.

- There appears to be no opportunity to share products and limited opportunities to share stock pieces[39], between customers in Europe. This was totally unexpected and limits the opportunities to combine orders or utilize flexible stock pieces between customers. It is important to note that although the analysis showed limited opportunities to share products between European customers, the possibility sharing the products with US customers was not examined.

- There is an extensive use of stock pieces by the AISC for "Customer C" (due to the Cut-To-Size Program with "Location 3") since only 313 different product specifications are produced at Davenport for "Customer C" even though they receive 1157 different product specifications from the European warehouse.

**Figure 4.2-1: Breakdown of Products for the Big Three Customers**

| | Number of Specifications | | |
|---|---|---|---|
| | 1999 Customer Demand | | |
| ORDER BREAKDOWN | "Customer C" | "Customer B" | "Customer A" |
| Product Number-Product Code-Alloy-Temper-Alclad-Gauge-Width-Length | 1,157 | 162 | 377 |
| Product Number-Product Code-Alloy-Temper-Alclad-Gauge | 231 | 77 | 264 |
| Alloy-Temper-Alclad-Gauge | 186 | 65 | 231 |
| 12 (PLATE) | 1,037 | 121 | 96 |
| 14 (SHEET) | 120 | 41 | 281 |

NOTES:
1. Data is for 1999 only (as of 23 September 1999).
2. There are no PN-PC- Alloy-Temper-Alclad-Guage-Width-Length combinations shared among the Big Three (when looking at all PO's and SO's):
3. There are 21 Alloy-Temper-Alclad-Guage combinations shared among the Big Three (when looking at all PO's and SO's):
   - 6 between "Customer C" and "Customer B"
   - 13 between "Customer B" and "Customer A"
   - 1 Between Customer C" and Customer A"
   - 1 between all three
   - Total Volume of shared specifications is 2,211,375 (11.04% of total volume)
4. For "Customer C": They only order 313 product specifications from Davenport (202 Plate and 111 Sheet).

I also analyzed the product mix in terms of volume to see if the majority of the order volume (in terms of weight) was contained in a relatively small number of product specifications. If this were the case, the utilization of some form of stocking policy could be easily implemented for the high volume products. Unfortunately, the order volume was spread across numerous products rather than a small minority (with the exception of "Customer C" where 848 product specifications accounted for only 5% of the order volume). Instead of following the 80-20 rule (80% of the volume in 20% of the

[39] Stock pieces can be differentiated by Alloy-Temper-Alclad-Gauge combinations. This however is a liberal definition of a stock piece because it ignores product code and country specific specifications (i.e., German metal cannot be given to the French, even if it is the exact same piece of metal that has undergone the exact same processing and testing, unless the metal is re-certified to the French specifications).

products), for "Customer B" it was 80-30 and for "Customer A" it was 80-33. This makes it difficult to determine which products should be kept in inventory. I also examined the potential benefits of utilizing stock pieces (with a stock piece being a PC-Alloy-Temper-Alclad-Gauge combination) within a designated customer's particular product mix. This analysis showed that there would be significant benefits from a flexibility and inventory stocking perspective by maintaining stores of stock pieces rather than stores[40] of end product specifications for each of the Big three customers. The results of this analysis are shown in Figure 4.2-2.

I also examined the annual usage (pounds per year) of products for "Customer A". The analysis (See Figure 4.2-3) showed that approximately 74% of the products for "Customer A" had an annual usage below Davenport Work's minimum order quantity of 4000 pounds. This is a significant contributor to overage being produced at Davenport works and FGI being carried at the European warehouse for "Customer A".

**Figure 4.2-2: Order Volume Analysis for the Big Three Customers**

**Number of Products (PN-PC-Alloy-Temper-Alclad-Gauge-Width-Length)**

| Percent of Ordered Weight (Total Volume in Pounds) | "Customer C" | "Customer B" | "Customer A" | Number of Potential Stores |
|---|---|---|---|---|
| 50% | 44 | 14 | 37 | 95 |
| 75% | 105 | 38 | 104 | 247 |
| 80% | 130 | 48 | 126 | 304 |
| 90% | 211 | 79 | 190 | 480 |
| 95% | 309 | 104 | 240 | 653 |
| 100% | 1157 | 162 | 377 | 1696 |

**Number of Stock Specifications (PC-Alloy-Temper-Alclad-Gauge)**

| Percent of Ordered Weight (Total Volume in Pounds) | "Customer C" | "Customer B" | "Customer A" | Number of Potential Stores |
|---|---|---|---|---|
| 50% | 27 | 6 | 20 | 53 |
| 75% | 57 | 17 | 63 | 137 |
| 80% | 66 | 20 | 80 | 166 |
| 90% | 95 | 33 | 129 | 257 |
| 95% | 119 | 44 | 166 | 329 |
| 100% | 209 | 77 | 264 | 550 |

[40] A store is a stack of inventory of a specific item.

**Figure 4.2-3: Volume Analysis for "Customer A"**

| Annual Usage (Pounds) | Number of Specifications | Number of Orders | Average Number of Orders Per Specification | Total Volume | Percentage of Volume | Cumulative Percent Volume | Cumulative Percent Specifications |
|---|---|---|---|---|---|---|---|
| 0-500 | 66 | 67 | 1.02 | 20,582 | 1.29% | 1.29% | 17.51% |
| 500-1000 | 55 | 75 | 1.36 | 41,604 | 2.60% | 3.89% | 32.10% |
| 1000-1500 | 38 | 64 | 1.68 | 48,019 | 3.00% | 6.89% | 42.18% |
| 1500-2000 | 31 | 46 | 1.48 | 55,005 | 3.44% | 10.33% | 50.40% |
| 2001-2500 | 30 | 61 | 2.03 | 67,404 | 4.21% | 14.54% | 58.36% |
| 2501-3000 | 28 | 49 | 1.75 | 77,726 | 4.86% | 19.40% | 65.78% |
| 3001-3500 | 13 | 28 | 2.15 | 42,632 | 2.67% | 22.07% | 69.23% |
| 3501-4000 | 18 | 46 | 2.56 | 68,027 | 4.25% | 26.32% | 74.01% |
| 4001-4500 | 7 | 10 | 1.43 | 30,110 | 1.88% | 28.20% | 75.86% |
| 4501-5000 | 7 | 14 | 2.00 | 32,622 | 2.04% | 30.24% | 77.72% |
| 5001-5500 | 8 | 29 | 3.63 | 42,369 | 2.65% | 32.89% | 79.84% |
| 5501-6000 | 10 | 33 | 3.30 | 57,375 | 3.59% | 36.47% | 82.49% |
| 6001-6500 | 10 | 37 | 3.70 | 62,959 | 3.94% | 40.41% | 85.15% |
| 6501-7000 | 6 | 25 | 4.17 | 40,685 | 2.54% | 42.95% | 86.74% |
| 7001-7500 | 5 | 11 | 2.20 | 36,728 | 2.30% | 45.25% | 88.06% |
| 7501-8000 | 3 | 6 | 2.00 | 23,363 | 1.46% | 46.71% | 88.86% |
| 8001-8500 | 3 | 7 | 2.33 | 25,278 | 1.58% | 48.29% | 89.66% |
| 8501-9000 | 1 | 6 | 6.00 | 8,987 | 0.56% | 48.85% | 89.92% |
| 9001-9500 | 2 | 8 | 4.00 | 18,806 | 1.18% | 50.03% | 90.45% |
| 9501-10000 | 1 | 5 | 5.00 | 9,593 | 0.60% | 50.63% | 90.72% |
| 10001-15000 | 18 | 65 | 3.61 | 219,014 | 13.69% | 64.32% | 95.49% |
| 15001-20000 | 8 | 34 | 4.25 | 140,876 | 8.81% | 73.13% | 97.61% |
| 20001-30000 | 3 | 17 | 5.67 | 67,287 | 4.21% | 77.33% | 98.41% |
| 30001-50000 | 1 | 4 | 4.00 | 33,599 | 2.10% | 79.43% | 98.67% |
| 50001-75000 | 4 | 26 | 6.50 | 224,796 | 14.05% | 93.49% | 99.73% |
| >75000 | 1 | 8 | 8.00 | 104,213 | 6.51% | 100.00% | 100.00% |
| | 377 | 781 | | 1,599,659 | 100.00% | | |

## 4.2.2: Cost Breakeven Analysis

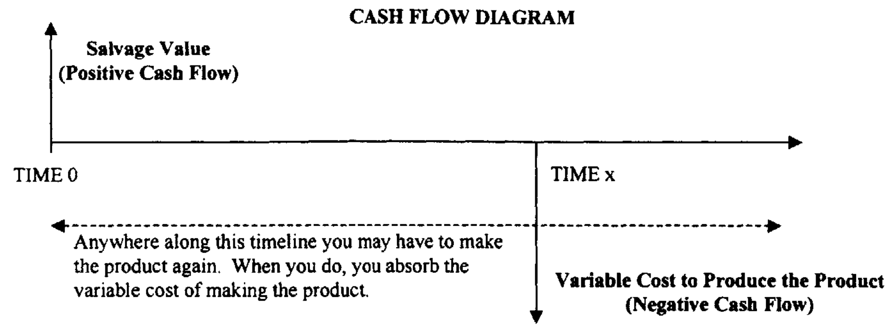
During the analysis the question of whether excess metal should be scrapped or kept in inventory was specifically addressed by performing a cost breakeven analysis. To perform the cost analysis the product mix of the three largest customers were broken down into eleven general categories. Then, a specific product specification (from actual customer orders) within each of the general categories was chosen. The specific product specifications were given to the Accounting Group to determine the variable production cost for each product specification. By applying that cost to all the products within the corresponding general category, a variable production cost was established for each general category of products. Figure 4.2-4 shows the breakdown of the general product categories, the specific product specifications chosen from the product mix, and the variable production cost for each product specification (and hence each general product category).

**Figure 4.2-4: General Product Categories and Corresponding Variable Production Costs for the Cost Breakeven Analysis**

| Product Categories: | Poduct Specification (Product Number, Product Code, Alloy, Temper, Alclad, Gauge, Width Length) | Variable Production Cost (Dollars) |
|---|---|---|
| **HEAT TREATED PLATE (Non-Skin):** | | |
| Product Category 1 | Product Specification 1 | $1.10 |
| Product Category 2 | Product Specification 2 | $1.38 |
| Product Category 3 | Product Specification 3 | $1.07 |
| **FLAT SHEET:** | | |
| **SKIN:** | | |
| Product Category 4 | Product Specification 4 | $2.22 |
| Product Category 5 | Product Specification 5 | $1.75 |
| Product Category 6 | Product Specification 6 | $2.89 |
| Product Category 7 | Product Specification 7 | $5.93 |
| **NON-SKIN, MILL FINISHED, ALCLAD** | | |
| Product Category 8 | Product Specification 8 | $1.95 |
| Product Category 9 | Product Specification 9 | $2.28 |
| **NON-SKIN, MILL FINISHED, BARE** | | |
| Product Category 10 | Product Specification 10 | $1.38 |
| Product Category 11 | Product Specification 11 | $1.87 |

The methodology utilized for the cost breakeven analysis was just the simple application of discounted cash flows coupled with a cash flow diagram. The breakeven methodology is shown in Figure 4.2-5 and the results after applying the methodology is shown in Figure 4.2-6. Based on the results of this analysis, there is strong support that once a product is produced it should be held in inventory rather than scrapped.

## Figure 4.2-5: Breakeven Analysis Methodology




**How to determine Net Present Value (NPV)**
**(i.e. how much is it worth today):**
•Variables:
C = Cash Flow (in dollars)
i = discount rate = cost of capital
x = time (in years)
•NPV = (C) / (1 + i)^x

**To find the break-even point:**
•Find the NPV of the two cash flows:
•Positive Cash Flow is the Salvage Value
•Salvage Value = (Metal Value)*(1-Melt Loss)
•Negative Cash Flow is the Variable Cost (C) to produce the product.
•Set the two NPVs equal to each other and solve for x.
•**Salvage Value** = (C) / (1 + i)^x
x = [LOG (Variable Cost/Salvage Value)] / [LOG (1+i)]

**What does this analysis tell me?**
•If I plan to sell the extra metal within x years, I should not have scrapped it.
•If I do not think that I will be able to sell the metal within x years, I should scrap excess metal today and send the scrap to be re-melted at the Ingot Plant.

## Figure 4.2-6: Results of the Cost Breakeven Analysis

**Critical Variables:**

| | |
|---|---|
| i = discount rate = cost of capital = | 0.12 |
| Metal Cost (dollars per pound) = | 0.725 |
| Melt Loss = | 0.05 |
| Gain From Salvage (1 - Melt Loss) = | 0.95 |

| Product Categories: | Poduct Specification (Product Number, Product Code, Alloy, Temper, Alclad, Gauge, Width Length) | Variable Production Cost (Dollars) | Break-Even Point (Years) |
|---|---|---|---|
| **HEAT TREATED PLATE (Non-Skin):** | | | |
| Product Category 1 | Product Specification 1 | $1.10 | 4.13 |
| Product Category 2 | Product Specification 2 | $1.38 | 6.13 |
| Product Category 3 | Product Specification 3 | $1.07 | 3.87 |
| **FLAT SHEET:** | | | |
| **SKIN:** | | | |
| Product Category 4 | Product Specification 4 | $2.22 | 10.32 |
| Product Category 5 | Product Specification 5 | $1.75 | 8.24 |
| Product Category 6 | Product Specification 6 | $2.89 | 12.65 |
| Product Category 7 | Product Specification 7 | $5.93 | 19.00 |
| **NON-SKIN, MILL FINISHED, ALCLAD** | | | |
| Product Category 8 | Product Specification 8 | $1.95 | 9.17 |
| Product Category 9 | Product Specification 9 | $2.28 | 10.57 |
| **NON-SKIN, MILL FINISHED, BARE** | | | |
| Product Category 10 | Product Specification 10 | $1.38 | 6.10 |
| Product Category 11 | Product Specification 11 | $1.87 | 8.79 |

However, this analysis assumes that the scrap decision is made at the end of the production process (i.e., the product is already made and we must now decide what to do with it). The analysis does not account for scrapping the metal at some point in the production process. For example, if a customer wants a quantity of metal smaller than the minimum order quantity (lets say the customer wants 2000 pounds and the minimum order quantity is 10000 pounds) we could scrap 80% of the ingot at some point in the production process. An idea would be to scrap 80% of the ingot after it goes through the hot line. The scrapped metal can be sent back to the ingot plant where approximately 5% will be lost due to melt loss and the rest of the metal can continue through the flowpath to get to the end customer requirement of 2000 pounds. I think there are two reasons why this would not be done. First, doing this would have an extremely negative impact on recovery at Davenport Works. Second, since the production yields are variable, there would be reluctance to scrap 80% of the ingot for fear of coming up short at the end.

In addition, the analysis does not take into account the impact of the scrap decision on capacity. There is limited capacity at Davenport Works; and during times of heavy bookings, capacity is a constraint that limits bookings. The fact that there is limited capacity gives more weight to the decision of not scrapping metal because you do not want to waste capacity on metal that you previously had and then scrapped.

## 4.3: Chapter Summary

The Big Three customers constitute the majority of AMP's European business in terms of both dollar value and product volume. Due to the criticality of the Big Three to AMP's European business, AMP is striving to best meet the needs of these three customers; however, the customer needs present significant supply chain challenges to AMP. Firstly, a different sales manager handles each customer and therefore, inconsistencies develop with how AMP deals with supply chain issues for different customers. Secondly, the customer contracts are complex, difficult to understand, and often times not strictly adhered to. Thirdly, customer needs are difficult to meet. The customers needs require the AMP supply chain to provide 100% service levels, JIT deliveries, the flexibility to cut end product specifications from designated stock pieces, and order quantities less than the mill minimum order quantities established by Davenport Works.

Furthermore, the product breakdown for these three customers is extremely broad; and there are very limited opportunities to share products between European customers. This broad product mix, which differs from customer to customer, increases the complexity of information flow, manufacturing, and inventory management.

To countermeasure these challenges (as well as the variability within the AMP supply chain), AMP utilizes inventory throughout the supply chain. Often times, inventory may sit for a period of years before it is delivered to the customer. Despite this, the analysis showed that if there is an expectation that there will be demand for the inventory in the future, then from an economic perspective it is better to hold the inventory rather than scrap the metal.

Unfortunately, there is only so much inventory that can be held before it becomes economically infeasible. Therefore, AMP is struggling with how to satisfy the customer needs of their key customers without maintaining excessive amounts of inventory in the supply chain. Chapter five will show a methodology to engineer inventory levels by product and demonstrate how the variability within the AMP supply chain makes these challenges even more difficult. Chapter six will discuss some recommendation for improvement that can assist AMP in satisfying their customer's needs while maintaining reasonable inventory levels.

# CHAPTER FIVE Development of the Methodology to Engineer Inventory Levels with Supply Chain Variability

One of the primary objectives for this research was to develop a methodology to engineer inventory levels by product. The base stock model is an excellent tool that can be used to engineer inventory levels by product. In addition, past LFM theses by Brian Black (1998) and Mark Graban (1999) have made adaptations to the base stock model to account for both production yield variability and lead time variability (both are assumed to be negligible with the original formulation of the base stock model). The nominal inventory levels depend on certain parameters within your supply chain (average demand, demand variability, lead time, lead time variability, production yields, yield variability, and the service level you want to provide to your customers). The significant impact that variability can have on the supply chain, and in particular inventory requirements, is often not understood and underestimated. Even though engineered inventory levels can be calculated, the results may be economically infeasible to put into practice. Therefore, the use of a methodology to engineer inventory levels is valuable in terms of establishing stocking policies as well as identifying improvement opportunities to improve the entire supply chain.

## 5.1: Why would a methodology be helpful?

As I conducted my research and began to develop a better understanding of the AMP supply chain for European customers, it became clear that there was no formalized inventory management system to guide behavior with regards to inventory. Most of the inventory management policies (i.e. padding lead times and padding order quantities) were being applied on a case by case basis and were based on past experiences and intuition rather than established methodologies and systems. As a result, the potential for inconsistencies existed in inventory management procedures for different locations and for different customers. This was primarily due to two reasons. Firstly, each individual stage within the supply chain approached inventory issues from the limited perspective of their own boundaries. This can be attributed more to a lack of knowledge about upstream and downstream stages within the supply chain as opposed to an unwillingness to cooperate. Secondly, there seemed to be varied levels of understanding about the reasons why you maintain inventory in the supply chain and how other variables within the supply chain (customer demand, lead-time, production yield, service level, and variability) impact inventory requirements.

AMP, like many other organizations, wants to reduce inventories within their supply chain. However, before removing inventory from the supply chain we must do two things. Firstly, we must understand the reasons why the inventory is there in the first place. Secondly, we must gain an understanding of what effects removing inventory will have on the other stages in the supply chain and most importantly how it will effect the service levels we provide to the end customers. A model is an effective tool that can help make inventory decisions in the supply chain for the following reasons:

- A model allows the analysis of multiple variables simultaneously in a systematic manner. It provides a framework to characterize inventory requirements in terms of customer demand, lead time, production processes (yields, constraints), customer service levels, and variability. The use of the model will demonstrate that inventory requirements are just a by-product of the supply chain system. The inventory itself is not the problem, but rather the result of other root cause problems within the supply chain. The application of a model can help identify those root cause problem areas.

- Use of a model will facilitate consistency in inventory management procedures across the entire supply chain. In addition, rather than solely relying on intuition and past experience, inventory decisions can be rationalized with quantitative analysis and information.

- A model gives you the ability to quickly perform sensitivity analysis and demonstrate how the different supply chain variables interact and impact inventory requirements. This ability allows you to better evaluate the trade offs being considered in the decision making process.

## 5.2: An Overview of the Original Base Stock Model

The methodology I chose to work with in engineering inventory levels by product for the AMP supply chain was the base stock model. The base stock model is relatively simple to apply (once you obtain the necessary data, which may not be so simple) and serves as an effective learning tool to demonstrate how different variables in the supply chain impact inventory requirements. The basic idea behind the base stock model is to set the Base Stock Inventory Level (B) to cover demand over the replenishment lead time[41] most of the time. The Base Stock Inventory Level consists of both WIP inventory and FGI (FGI is comprised of both cycle stock and safety stock). Safety stock is the inventory you would expect to have remaining just prior to replenishment.

**Base Stock Model Assumptions:**

- Demand roughly follows a normal distribution with a mean of $\mu$ and a variance of $\sigma^2$ per unit time. This is why we can use the z factor from the normal distribution table to represent service level requirements.
- The replenishment lead time (L) is known and fairly constant (not highly variable).
- Yield variability is not accounted for and is therefore implicitly assumed to be negligible.
- There are no capacity constraints for manufacturing (i.e., there will always be enough capacity to produce what the model dictates).
- The base stock model can assume either a periodic review system or a continuous review system.
- Replenishment orders are placed each period. With a periodic review system, replenishment orders are placed on a regular cycle after each review period (r). The quantity ordered is equal to the demand over the review period. With a continuous review system, replenishment orders are placed when the inventory (WIP inventory plus FGI) reaches a designated reorder point (R). The order quantity is constant and equal to a quantity we will call Q. (*A continuous review system is actually referred to as a (Q,R) model rather than a base stock model.*)

[41] Replenishment lead time represents the time from when the customer requests a specific item until the time that the specific item is delivered to the customer.

**Base Stock Model Variable Definitions:**

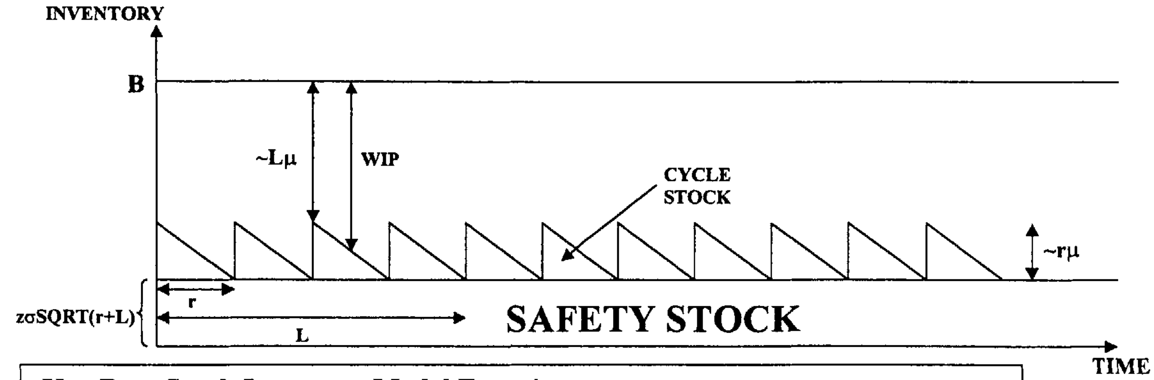
- E(FGI) = Expected Finished Goods Inventory Level (Safety Stock plus Cycle Stock)
- B = Base Stock Inventory Level
- $\mu$ = Mean of Demand
- $\sigma$ = Standard Deviation of Demand
- L = Replenishment Lead Time (Time from order being placed to the order being delivered to the customer)
- r = Review Period (The time between orders being placed.)
- z = Service Level Indicator
  - z = .675 (75% Service Level)
  - z = 1.28 (90% Service Level)
  - z = 1.64 (95% Service Level)
  - z = 2.33 (99% Service Level)

**Base Stock Inventory Formula:**

$$B = [(\mu)(r + L)] + [(z)(\sigma)\,\mathrm{SQRT}(r + L)]$$

Figure 5.2-1 provides a graphical representation of the base stock model as well as the key equations used in its application.

**Figure 5.2-1: Graphical Representation of the General Concept of the Base Stock Model with Key Equations**[42]




**Key Base Stock Inventory Model Equations:**

•Set B to cover demand over the replenishment lead time (to prevent stockouts):

| | |
|---|---|
| •Demand over Lead Time | $= \mu * (r + L)$ |
| •Variance over Lead Time | $= \sigma^2 * (r + L)$ |
| **•Base Stock Inventory Level** | $= B = [\mu * (r + L)] + [z * \sigma * SQRT(r + L)]$ |
| •Expected FGI Level = E(FGI) | = Cycle Stock + Safety Stock |
| •Cycle Stock | $= (r)(\mu/2)$ |
| •Safety Stock | $= z * \sigma * SQRT(r + L)$ |
| **•Expected FGI Level** = E(FGI) | $= [(r)(\mu/2)] + [z * \sigma * SQRT(r + L)]$ |

There are several key points I would like to discuss concerning the base stock model. Firstly, the model has a customer service focus rather than a cost focus. The model determines the base stock inventory level (B) that is required to achieve a desired customer service level. In contrast, many inventory models focus on costs by creating a total cost function and then determining the inventory level that minimizes cost.[43] Working with a model that has an external customer focus rather than an internal cost focus is more consistent with how AMP wants to approach their business.

Secondly, the type of review system that is utilized (periodic or continuous) has an impact on how the model operates. The primary difference between a periodic review system and a continuous review system is the lead time element. With a periodic review system, the lead time element is (r + L) (the review period plus the replenishment lead

[42] This information was obtained from Steve Graves' 15.762 (Operations Management Models and Applications) Lecture Notes, Spring 1999.

time). The level of inventory (WIP inventory and FGI) is reviewed and replenishment orders equal to the demand since the last replenishment are placed on a regular cycle (at t = 1r, 2r, 3r, etc.). The periodic review system is similar to how a pull system operates in discrete time.[44] With a continuous review (Q,R) system, the lead time element is solely L (the replenishment lead time). The level of inventory is continually assessed and known at any point in time. Replenishment orders are placed when the level of inventory dips below a designated reorder point (R). Although the capabilities are in place to determine what is in WIP and what is in FGI within the AMP supply chain at any given point in time, it is not a simple task. No one individual has access to all the necessary information and the information has to be drawn from multiple databases that are not compatible. The difficulty in obtaining information coupled with the large number of products being dealt with makes it currently infeasible to operate under a continuous review system. As a result, I would recommend for AMP to operate the base stock model under a periodic review system.

Thirdly, the quantity ordered is generally a function of the level of demand since the last replenishment (i.e., demand over the review period (r)). However, Davenport Works operates under the principle that production is initiated in increments of the yield (recovery) of an ingot. As a result, the order quantity needs to be a function of both the yield of an ingot and the customer demand over the review period. The order quantity must be an amount that is both a multiple of the yield of an ingot and greater than or equal to the demand over the review period. Since ingot yields may not coincide exactly with customer demand, there will be replenishment orders that exceed the demand over the review period. This excess metal will continue to accumulate unless it is tracked and all subsequent orders take this excess metal into account.

---

[43] Hopp and Spearman, 77.
[44] This information was obtained from Steve Graves' 15.762 (Operations Management Models and Applications) Lecture Notes, Spring 1999.

**Example**:

- Assume the ingot yield for a particular product is 7000 pounds per ingot.
- If D (0,r)[45] equals 10,000 pounds, then at (t = r) we would place an order for 14,000 pounds (2x7000 pounds).
- If D(r, 2r) equals 11,000 pounds, then at (t = 2r) we would place an order for only 7,000 pounds (1x7000 pounds). Since we had 4000 pounds excess from the previous replenishment order, we only had to order one ingot's worth of production.

To ensure that the excess metal is not neglected when placing replenishment orders, I have established a general rule of thumb to help determine the amount of each replenishment order.

**General Rule of Thumb when Placing Replenishment Orders:**

At the end of each review period, place a replenishment order that satisfies the following relationship:

**(Cumulative demand since the prior review period.) – (Excess metal from the last order)**

**<= (Number of Ingots Worth of Production) (Ingot Yield)**

Finally, the base stock formula demonstrates that if inventory levels are reduced without changing one or more of the other variable in the supply chain, customer service levels will be negatively impacted.[46] According to the original formulation of the base stock model, there are only four ways to reduce inventory in the supply chain without negatively impacting customer service level.

1. Average demand ($\mu$) is reduced.
2. The standard deviation of demand ($\sigma$) is reduced.
3. The review period (r) is decreased.
4. The replenishment lead time (L) is decreased.

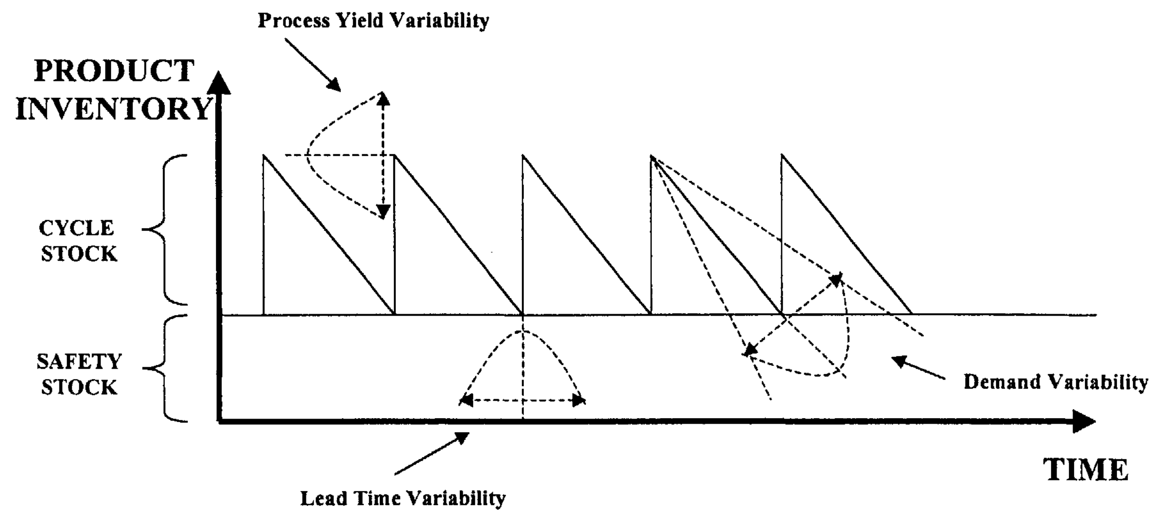
[45] D(0,r) represents the demand over the review period (from time zero to time r).
[46] The exception to this rule is if you are reducing inventory by removing dead stock. Removing dead stock with all other variables remaining equal will not negatively impact customer service levels since there is no demand for the inventory you are eliminating.

If inventory is reduced without one of these corresponding events occurring; customer service levels will decrease. This is the approach that needs to be taken when considering inventory reductions. This is also why many inventory reduction initiatives fail. **The focus needs to be on the factors in the supply chain dictating the inventory requirements rather than the inventory itself.** As was stated in chapter 2, inventory requirements are a by-product of the supply chain. The characteristics of the supply chain must be changed before inventory requirements can be altered.

## 5.3: Variability in the AMP Supply Chain

Many individuals underestimate both the presence and impact of variability on the supply chain. There are three primary sources of variability in the AMP supply chain: demand variability; production yield variability; and lead time variability. Each source of variability needs to be examined to perform a comprehensive supply chain analysis. Inventory is a tool that can be used as a countermeasure to variability in the supply chain; however, high levels of variability require high levels of inventory to countermeasure that variability and maintain desired customer service levels. Inventory models generally assume that inventory patterns for cycle stock can be represented by a general saw tooth diagram as shown in Figure 5.2-1. In reality, this assumption may not hold true. The presence of variability significantly alters the shape of the saw tooth diagram causing numerous supply chain problems and negatively impacting inventory requirements. Figure 5.3-1 shows how each type of variability alters the saw tooth diagram and impacts order patterns and inventory levels. The magnitude of the variability dictates how broad the corresponding distributions on the diagram will be.

**Figure 5.3-1: Sources of Variability in the Supply Chain**[47]




There is no simple inventory model presented in the manufacturing literature that can be applied to account for all three types of variability simultaneously. The original base stock model only takes into account demand variability and as a result, would fail to include the additional inventory needed to compensate for production yield variability and lead time variability. Fortunately, work has been done on the original base stock model to account for all three types of variability simultaneously. Brian Black (LFM 1998) developed an adaptation of the original base stock model to account for production yield variability and Mark Graban, building on Black's work, developed an extension of the model to account for lead time variability. Overviews of these extensions to the original base stock model are described in Appendices A and B respectively.

This section examines the three primary sources of variability within the AMP supply chain and demonstrates how variability can impact inventory requirements. The analysis argues that the presence of significant variability within the AMP supply chain challenges the feasibility of operating a base stock inventory management system due to the excessive amounts of inventory needed to countermeasure the variability. The need to hold inventory as a countermeasure to variability may partially explain why most

[47] This graph is an adaptation of a graph in Mike Miller's (LFM 1997) thesis, "Business System Improvements Through Recognition of Process Variability", page 23.

inventory models do not account for significant variability. It is often better to work on root cause problems to reduce variability before extensive use of inventory models is applied.

### 5.3.1: Demand Variability

To examine the demand variability I utilized the coefficient of variation to categorize each product as an A, B, or C item based on the level of variability associated with the demand for that particular product. The coefficient of variation can be utilized as a relative measure of variability of a random variable.[48] The coefficient of variation is defined as the standard deviation divided by the mean.

| | | |
|---|---|---|
| **Coefficient of Variation** = **CV** = | | $\sigma/\mu$ |
| $\sigma$ | = | Standard Deviation of demand over a period of time t. |
| $\mu$ | = | Average Demand over a period of time t. |

Ideally, we want the CV to be as low as possible because the higher the CV the more variable the demand. The coefficient of variation can be utilized to classify items as either A items, B items or C items based on how variable the demand is for each item. The following classification criteria was utilized[49]:

| | | | | | |
|---|---|---|---|---|---|
| A Items: | CV | <= | 0.75 | | |
| B Items: | 0.75 | < | CV | <= | 1.25 |
| C Items: | CV | > | 1.25 | | |

A items would be considered "fast movers" with relatively stable demand. B and C items would be considered "slow movers" with extremely variable demand. Items with a low CV (i.e., A items) can be made to stock utilizing a base stock policy and not require excessive amounts of inventory. Items with a high CV (i.e, B and C items) pose more of a problem from a supply chain management perspective. If the B and C items are low volume items, make to order would be the best case if the market permits. However, if there is a mismatch between the order quantity and the production quantity (order

[48] Hopp and Spearman, 251.

quantity < production quantity) then there will be significant overage stocks for these items. If the B and C items were high volume items, then it would be best to investigate why the CV's are so high and then examine techniques to either lower the CVs or better forecast the requirements. The results of the CV analysis applied to all of the items ordered for the Big Three customers are shown in Figure 4.2-4.

**Figure 5.3-1: ABC Item Breakdown Utilizing the Coefficient of Variation**

| Classification Criteria | "A" ITEMS | "B" ITEMS | "C" ITEMS | % "A items" |
|---|---|---|---|---|
| **"Customer A":** | | | | |
| PN-PC-Alloy-Temper-Alclad-Gauge-Width-Length | 3 | 16 | 267 | 1.05% |
| PC-Alloy-Temper-Alclad-Gauge | 2 | 16 | 185 | 0.99% |
| **"Customer B":** | | | | |
| PN-PC-Alloy-Temper-Alclad-Gauge-Width-Length | 11 | 34 | 80 | 8.80% |
| PC-Alloy-Temper-Alclad-Gauge | 12 | 16 | 32 | 20.00% |
| **"Customer C":** | | | | |
| PN-PC-Alloy-Temper-Alclad-Gauge-Width-Length | 26 | 202 | 897 | 2.31% |
| PC-Alloy-Temper-Alclad-Gauge | 32 | 53 | 108 | 16.58% |

This analysis shows two things. Firstly, demand is extremely variable because there is a relatively small amount of A items in the entire product mix. Secondly, there are potential benefits to managing inventory by stock pieces from a demand variability perspective. By maintaining inventory for stock pieces as opposed to end product specifications, some B and C items move to an A item classification.

### 5.3.2: Production Yield Variability

Trying to quantify actual production yields and production yield variability was a difficult task. The first challenge was in how Davenport Works consolidates information on production yields. Throughout my work I operated under the assumption that Davenport Works produces in increments of a full ingot; and it is not common practice to target an ingot to be made to multiple product specifications.[50] While this is true, production is tracked throughout the facility by specific lots rather than by full ingots. Therefore, production yields are captured for individual lots. Since each ingot can be

[49] Hopp and Spearman, 257.

[50] An ingot is generally targeted to produce only one specific product. It is not common practice (although it does happen on occasion) to plan on using a fraction of a particular ingot to produce one specific product and the remainder to produce a different product.

used to produce one or more lots, it is difficult to determine the production yield of a particular ingot because of how the data is captured and presented. Fortunately, within the database, each lot contains a reference to the ingot from which it is produced. This reference is the ingot serial number. Through database queries and manual calculations, it is possible to obtain production yields for the majority of the ingots initiated in the production process. However, this procedure is not automated; and collecting the data and putting it into a form that facilitates analysis is extremely time consuming.

The second challenge is that the same type of ingot is not always used to produce a specific product. The type of ingot selected to initiate production of a particular product is a function of the type of product, the order size, and the current availability of ingots on the ingot pad. Based on the quantity of the end customer requirements for a particular product, the size of the ingot chosen for production will deviate accordingly (i.e., a larger ingot for larger orders and a smaller ingot for smaller orders). The size of the ingot impacts the magnitude of the production yield. In addition, ingot selection to initiate production for a particular product may be a function of current ingot availability on the ingot pad rather than the ingot selection made by LOT GEN. Furthermore, a particular type of ingot is used to produce a multitude of different products. Each product may go through a completely different production process resulting in different production yields for different products.

Despite the challenges, I attempted to develop a sense of both the presence and the magnitude of production yield variability at Davenport Works. I queried the Davenport Works database for all completed lots through mid-November in 1999. I separated the information into product categories (plate products and sheet products) resulting in a database of 46,044 plate lots and 37,415 sheet lots. I focused on analyzing production yield variability in terms of Alloy, Planned Ingot, and Production Flowpath. I felt these were the most relevant categories to break down production yield.[51]

I first examined the list of planned ingots for both plate and sheet products to determine how many of each type of ingot were used for 1999 completed lots. For plate

[51] All partial ingots and lots that were 100% scrapped were eliminated from the data sets.

products there were a total of 113 different planned ingots utilized with the top three ingot sizes comprising approximately 22% of the total ingots used. For sheet products there were a total of 185 different planned ingots utilized with the top three ingot sizes comprising approximately 28% of the total ingots used. The 80-20 rule applied for both types of products meaning that 80% of the ingots used came from only 20% of the total number of planned ingot types.

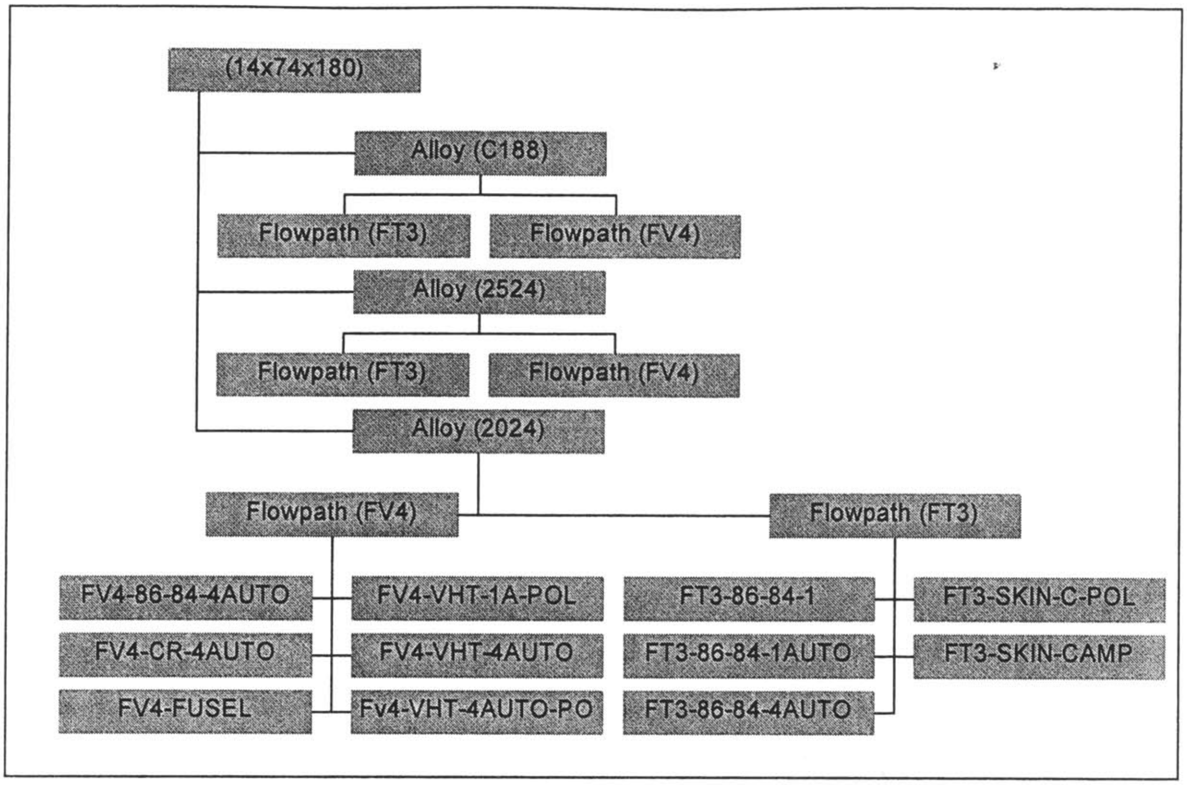
Once I got a sense of the relative use of the different planned ingot sizes, I wanted to examine if there were any evidence to suggest that production yields vary within a particular ingot size. I took the top three ingot sizes for each product group (plate and sheet) and generated descriptive statistics and histograms on production yields for planned ingot and alloy combinations. The following combinations were looked at:

- Planned Ingot: (14x74x180) Alloys: C188, 2524, 2024
- Planned Ingot: (16x50x180) Alloys: 2024, 7050, 7075
- Planned Ingot: (16x50x193) Alloys: 2324, 7050, 7150
- Planned Ingot: (16x50x128) Alloys: 2024, 7050, 7075, 7175,7475
- Planned Ingot: (16x60x180) Alloys: 2024, 2324, 7050, 7075
- Planned Ingot: (24x78x207) Alloys: 5452, 6061, 5052, 5083

The results showed extremely variable production yields for each planned ingot and alloy combination as evidenced by the histograms having broad, bell-shaped distributions.

Given these results, I decided to perform a more in-depth analysis on the most widely used planned ingot size. I expanded the analysis to include primary flowpaths and sub-flowpaths within a primary flowpath. I generated descriptive statistics and histograms on production yields[52] for each of the following combinations:

[52] Production yield is equivalent to recovery. Therefore, Production Yield = (Pack Weight) / (Gross Weight). Pack Weight is the amount of metal packed from a particular ingot. Gross Weight is the weight of the ingot after it has been scalped.




Again, the results showed extremely variable production yields for each combination as evidenced by the histograms having broad, bell-shaped distributions.

While the analysis on production yields showed some interesting results, a much more in-depth analysis needs to be conducted. Additional product specifications such as gauge, width, length, and lot completion date need to be examined in conjunction with planned ingot, alloy, and flowpath to gain a sense of the true production yield variability. Also, there was no way to distinguish between planned yield loss and unplanned yield loss based on how the data is collected. Since some of the variability shown in the histograms is planned, my analysis overstated the problem to some extent because I was unable to distinguish planned from unplanned yield loss. However, the data suggests that there may be significant production yield variability and until a more thorough analysis is conducted, the extent of the production yield variability will be unknown.

### 5.3.3: Lead Time Variability

A good deal of effort was spent establishing the replenishment lead time[53] for the AMP supply chain, which is approximately 125 days or 4.2 months. There are several factors that may cause this lead time to fluctuate, but I think two reasons constitute the majority of the lead time variability. Firstly, since production yields are variable, replenishment lead time may increase if a product has to be re-manufactured. In this case the replenishment lead time will increase by some portion of the lead time associated with Davenport Works where the product is actually manufactured.

Secondly, is what I call capacity constrained replenishment lead time, which results from the use of the OBT to book capacity at Davenport Works. The promise date for all orders is determined by the OBT, and hence, the OBT allocates the capacity of Davenport Works. The OBT reserves capacity by market on a first come first serve basis. Unfortunately, the OBT does not allocate capacity by customer and as a result has no sense of strategic value from a customer perspective. Key customers may be quoted longer lead times because less strategic customers happen to place their orders earlier. Capacity constrained lead time can come into play when the order book is booked to near full capacity.

For example, let's assume that the replenishment lead time is four months. If we require the customer to place firm orders six months out, there should be no problem satisfying orders for that particular customer (since the replenishment lead time is only four months). However, during heavy periods of demand, the OBT may book capacity several months out. As a result, the mill may not have available capacity to start production until three months from the time the order is received. Since you can't start production for another three months due to capacity constraints and your replenishment lead time is four months, it will take seven months from the time the customer submits the order to the time the customer receives the order. Therefore, due to capacity constraints, AMP may be unable to deliver products to a key customer who has entered

[53] As was stated earlier, replenishment lead time represents the time from when a customer requests a specific item to the time the specific item is delivered to the customer.

their order into the system six months out. This lead time variability is difficult to predict and can negatively impact customer service levels (especially key contract customers).

## 5.4: Application of the Base Stock Model

I worked through two examples to show the impact of variability on inventory levels within the supply chain. The two applications utilize the original base stock model rather than the adaptations of the model that account for lead time variability and production yield variability. Therefore, in these examples demand variability is the only type of variability we are protecting against with inventory. If the variations of the base stock model were used, even more inventory would be required because we would also have to protect against lead time variability and production yield variability (both of which do exist within the AMP supply chain). The purpose of this section is to apply the base stock model to demonstrate how variability can significantly impact inventory requirements.

### 5.4.1: Application of the Base Stock Model for a "A Item" (Relatively Low Demand Variability)

The purpose of this example is to provide a general sense of inventory requirements for an "A item" when a base stock methodology is applied. Figure 5.4-1 goes through the application of the base stock model on an actual product from one of the Big Three customers. The example assumes that at time zero all the base stock inventory was in FGI[54] and the month to month calculations are provided in Appendix C. The inventory graph exemplifies several key points:

- No stockouts occurred over the twelve-month period.
- Safety Stock represents a relatively small percentage of the total base stock inventory.
- The total base stock inventory level remains fairly stable around the calculated base stock inventory level but always higher. This suggests that we may be able to reduce safety stock a little bit.

[54] For both examples I assumed that at time zero the total base stock inventory was in FGI. This was done for two reasons. First, to show that due to the long replenishment lead time it takes a significant amount of inventory to initiate a base stock inventory system (it cannot be started immediately). Second, so that the specific calculations and their impact could be shown.

- The cycle stock follows a general saw tooth pattern with no wild fluctuations.
- The majority of the inventory is WIP inventory. This is primarily due to the fact that the replenishment lead time is so long (we assumed L = 4 months and r = 1 month).

**Figure 5.4-1: Original Base Stock Application for a "A Item"**

Product: (PN-PC-Alloy-Temper-Alclad-Gauge-Width-Length)
Product Specification "A Item"

Piece Weight = (Gauge) (Width) (Length) (0.1)*
= (3.937) (49.21) (98.43) (0.1)
= 1907 Pounds Per Piece

| DEMAND: | Month | |
|---|---|---|
| | January | 9,707 |
| | February | 11,649 |
| | March | 15,531 |
| | April | 13,197 |
| | May | 13,593 |
| | June | 15,626 |
| *(Assume the same demand pattern for the next six months)* | | |
| | July | 9,707 |
| | August | 11,649 |
| | September | 15,531 |
| | October | 13,197 |
| | November | 13,593 |
| | December | 15,626 |
| TOTAL ANNUAL DEMAND: | | 158,606 |

Average Monthly Demand = $\mu$ = 13,217
Standard Deviation of Demand = $\sigma$ = 2,284
Coefficient of Variation = CV = 0.17

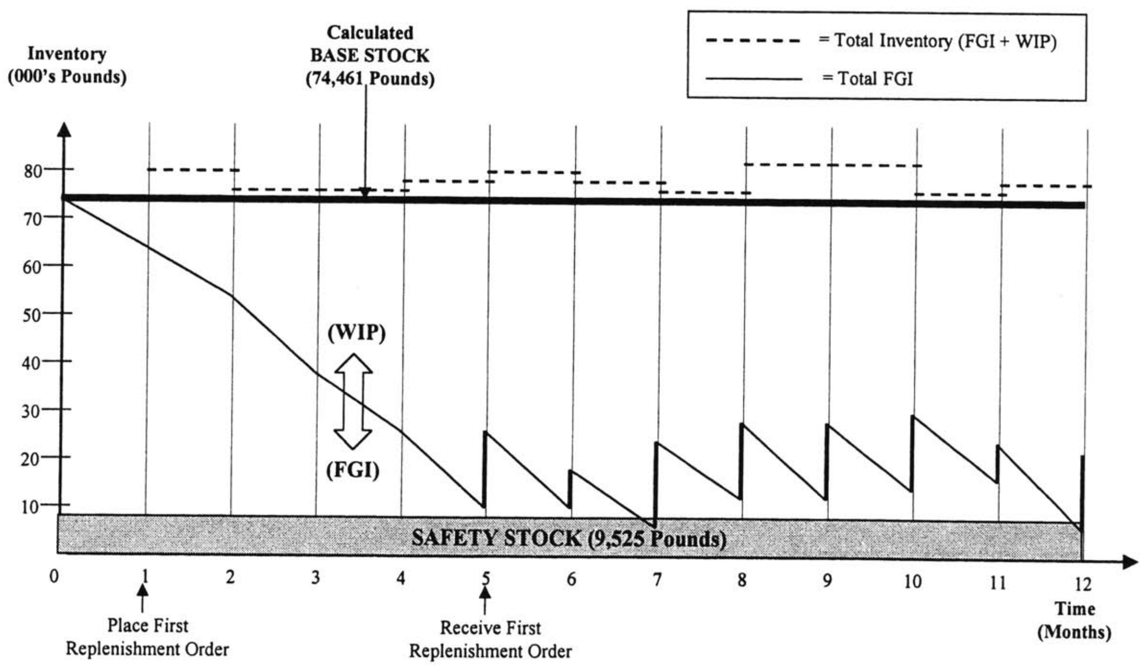
* *Piece Weight can be estimated by multiplying: (Gauge) (Width) (Length) (0.1)*

ASSUMPTIONS:
- •L = 4 months
- •r = 1 month
- •Ingot Yield = 7620 pounds
- •Service Level = 95%
- •Z value = 1.64

Order Quantity = Q
= (Ingot Yield) (Number of Ingots Started)

Base Stock Inventory Level:
B = $(r + L)\,\mu + (z)\,(\sigma)\,[\mathrm{SQRT}(r+L)]$
= $(1 + 4)\,(13217) + (1.64)\,(2284)\,[\mathrm{SQRT}(1+4)]$
= 74,461 Pounds
~ 39 Pieces

Safety Stock Level:
SS = $(z)\,(\sigma)\,[\mathrm{SQRT}(r + L)]$
= $(1.64)\,(2284)\,[\mathrm{SQRT}(1 + 4)]$
= 8376 Pounds
~ 4.4 Pieces
Therefore: Carry 5 Pieces in SS at 9525 Pounds



### 5.4.2: Application of the Base Stock Model for a "C Item" (Relatively High Demand Variability)

The purpose of this example is to provide a general sense of inventory requirements for a "C item" when a base stock methodology is applied. Figure 5.4-1 goes through the application of the base stock model on an actual product from one of the Big Three customers. The example assumes that at time zero all the base stock inventory was in FGI and the month to month calculations are provided in Appendix D. The inventory graph exemplifies several key points:

- No stockouts occurred over the twelve-month period.
- The calculated base stock inventory level is greater than the annual demand.
- Safety Stock represents a relatively large percentage of the total base stock inventory.
- The total base stock inventory level significantly deviates from the calculated base stock inventory level. From the start of month two to the start of month six the inventory in the system (WIP and FGI) is more than double the calculated base stock inventory level. For months six through twelve the amount of FGI is significantly greater than the calculated base stock inventory level.
- The level of cycle stock fluctuates wildly and does not follow a saw tooth pattern. FGI dips below the safety stock level for approximately half the time and then jumps to well above the base stock inventory level for the rest of the time.
- The majority of the inventory is FGI inventory. This is primarily due to the fact that the demand is low, demand is sporadic, and the order quantity is significantly greater than annual demand.

The application of the base stock model ensured that we maintained our desired service level (i.e., there was never a situation where we had a stockout). However, due to the irregular order patterns and significant variability associated with B and C items, it may be advantageous to set the base stock inventory level differently utilizing judgement and data rather than just purely statistics. For example, we could set the base stock inventory level to the maximum demand over a five month period (r + L). This may result in lower inventory levels without sacrificing customer service levels.

## Figure 5.4-2: Original Base Stock Application for a C Item

Product: (PN-PC-Alloy-Temper-Alclad-Gauge-Width-Length)
Product Specification "C Item"

Piece Weight = (Gauge) (Width) (Length) (0.1)*
= (0.048) (48) (144) (0.1)
= 33.2 Pounds Per Piece

| DEMAND: | | |
|---|---|---|
| | January | 0 |
| | February | 1,146 |
| | March | 0 |
| | April | 0 |
| | May | 0 |
| | June | 0 |
| *(Assume the same demand pattern for the next six months)* | | |
| | July | 0 |
| | August | 1,146 |
| | September | 0 |
| | October | 0 |
| | November | 0 |
| | December | 0 |
| TOTAL ANNUAL DEMAND: | | 0 |

Average Monthly Demand = μ = 191
Standard Deviation of Demand = σ = 468
Coefficient of Variation = CV = 2.45

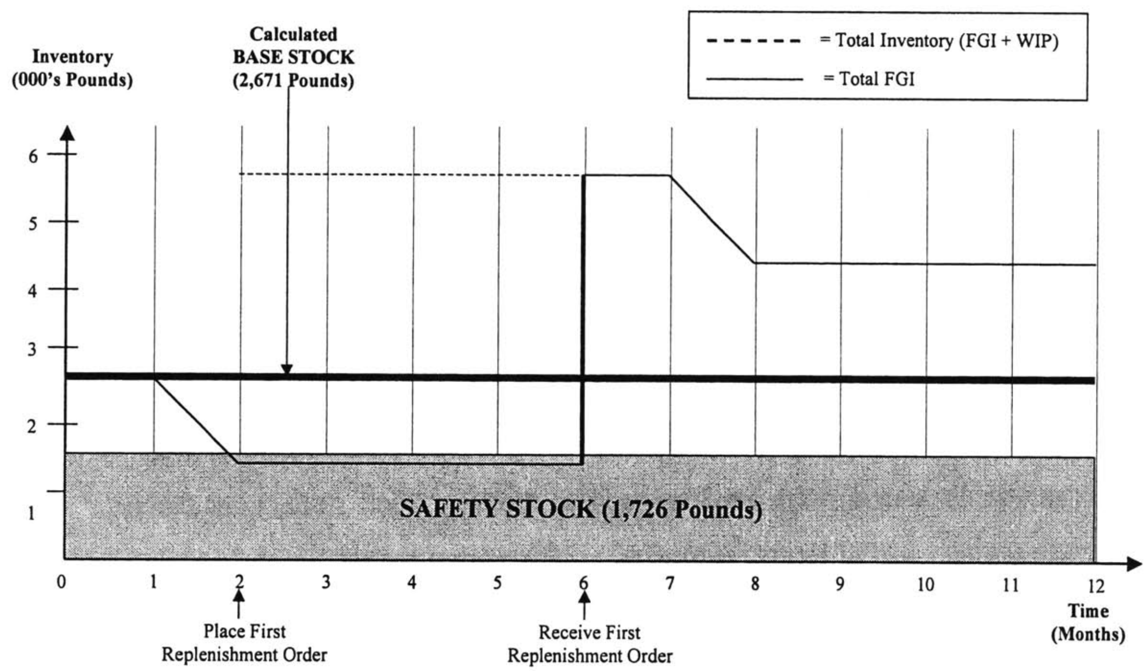
* *Piece Weight can be estimated by multiplying:*
*(Gauge) (Width) (Length) (0.1)*

ASSUMPTIONS:
- •L = 4 months
- •r = 1 month
- •Ingot Yield = 4150 pounds
- •Service Level = 95%
- •Z value = 1.64

Order Quantity = Q
= (Ingot Yield) (Number of Ingots Started)

Base Stock Inventory Level:
B = (r + L) μ + (z) (σ) [SQRT(r+L)]
= (1 + 4) (191) + (1.64) (468) [SQRT(1+4)]
= 2,671 Pounds
~ 80 Pieces

Safety Stock Level:
SS = (z) ( σ) [SQRT(r + L)]
= (1.64) (468) [SQRT(1 + 4)]
= 1716 Pounds
~ 51.7 Pieces
Therefore: Carry 52 Pieces in SS at 1726 Pounds



## 5.5: When should the Base Stock model be applied?

As the previous examples show, the base stock model can be applied to "A Items" without carrying excessive amounts of inventory. However, when the base stock model is applied to a "C Item" the results of the model dictate carrying excessive amounts of inventory to countermeasure the significant variability. In most cases, the costs to carry inventory on highly variable items are too great. As a result, the analysis would indicate that "C Items" should be produced on a make to order basis rather than a make to stock basis. Unfortunately, the market may not allow for items to be produced on a make to order basis if customers place orders in a time frame that is less than the replenishment lead time.

The examples only addressed demand variability but the same concept holds true for both lead time variability and production yield variability. Inventory must be maintained in the supply chain to countermeasure variability or customer service levels will decrease (assuming all else remains constant). Therefore, the application of the base stock model within a supply chain that contains significant amounts of variability (demand and/or lead time and/or production yield) will require excessive amounts of inventory. Since keeping excessive amounts of inventory is usually infeasible from a cost perspective, application of the base stock model may not be recommended and an analysis of the trade-offs between service levels and costs needs to be done before the decision can be made. One solution that can be examined (until variability in the supply chain is reduced) is to operate a make to order system for the majority of items and produce a small percentage of critical items according to a base stock methodology. However, as was discussed in the previous section, the base stock model may also be a feasible methodology for "C items" (especially if the market requires high levels of service) but the base stock inventory level would have to be set differently (i.e., use judgement and data rather than just statistics).

## 5.6: Chapter Summary

One of the primary objectives of this work was to develop a methodology to engineer inventory levels by product. The base stock model is an excellent tool to both show how basic supply chain variables impact inventory requirements and to determine engineered inventory levels through quantitative analysis. The adaptations to the base stock model for production yield variability and lead time variability by Brian Black (LFM 1998) and Mark Graban (LFM 1999) make the base stock model even more applicable to the real world supply chain environment.

However, variability in the supply chain requires the presence of inventory to countermeasure it. There is evidence of significant amounts of demand, production yield, and lead time variability within the AMP supply chain. To countermeasure this variability, excessive amounts of inventory must be maintained. The engineered inventory levels for the majority of products are infeasible from an economic perspective. As a result, the benefit of utilizing the model is more to identify areas that need to be improved rather than to calculate engineered inventory levels by product. Once the variability within the supply chain can be reduced, then the results of the base stock model can be applied in a rational manner. Chapter six provides several recommendations for improvement and future work that will help enable the supply chain to operate more efficiently and achieve a state where engineered inventory levels can be both calculated and applied.

# Chapter SIX: Recommendations for Improvement and Future Work

The analysis resulted in the development of several recommendations for improvement and future work. This portion of the analysis became increasingly important as problems became more accurately defined. This chapter categorizes the recommendations by specific location within the supply chain as well as recommendations that are applicable to the entire supply chain.

## 6.1: Davenport Works

### 6.1.1: Work on Reducing Production Yield Variability and Make It a Priority

There is evidence that a significant amount of yield variability exists within the production processes at Davenport Works. However, the magnitude of the yield variability is difficult to determine due to the challenges associated with collecting and analyzing the relevant data in an efficient manner. As a result, the production yield variability at Davenport Works is not clearly understood, so it is difficult to identify and address root cause problems.

Rather than focusing on production yield variability itself, a major focus at Davenport Works is on recovery.[55] One of the most important performance metrics at Davenport Works is maximizing recovery. Although recovery is often viewed in total, recovery should be broken down into engineered recovery and quality recovery. Engineered recovery is a function of the amount of metal that was lost as a result of the production process (i.e., side scrap, end scrap, etc.). Engineered recovery is something that is known, easy to identify and can be planned for. Quality recovery is a function of the amount of metal that was unexpectedly lost at some point in the production process. Quality recovery is an unknown, difficult to predict, and cannot be accurately planned for. Therefore, quality recovery is the source of unplanned production yield variability. Attacking the root cause problems that lead to metal loss because of quality recovery is a difficult task, but it is where the most benefits lie in terms of reducing production yield variability.

Unfortunately, the distinction between quality recovery and engineered recovery is lost because the two variables are aggregated and reported as a single value (total recovery). Since it is much easier to work on improving engineered recovery (for example, by increasing the number of different ingot sizes and working with tighter and tighter tolerances) that is where the emphasis has been on in the past. Recently however, the distinction between quality recovery and engineered recovery is being expressed and Davenport Works is beginning to undertake major improvement projects to identify root cause problems associated with quality recovery.

Improving quality recovery has customer service benefits as well. From a customer service perspective, you might rather have a predictable but low yield, than a higher yield that is highly variable. If recovery is 20%, I would prefer to know it is 20% and plan my production based on that, rather than being in a situation where my recovery is uncertain (it may be 60%, it may be 20%, or it may be 0%). The latter situation leads to poorer customer service, increased changes in the production schedule, an increased amount of expediting, and higher levels of employee stress throughout the plant.

Reducing yield variability by improving quality recovery has additional benefits in terms of customer service. If Davenport Works is urging the customer to order in increments of the recovery of an ingot, what quantity should they tell the customer to order? Since production yield graphs are bell-shaped (approximately normally distributed) and broad; this decision involves a trade-off analysis between inventory and customer service levels. If the customer orders in increments towards the low end of the distribution (smaller order quantities), customer service numbers should increase, but AMP will have to deal with more inventory. If the customer orders in increments towards the high end of the distribution (larger order quantities), customer service levels should decrease (because our yields will often be less than what they order) but AMP will

---

[55] As stated earlier, Recovery = (Pack Weight) / (Gross Weight). Pack Weight is the amount of metal packed from a particular ingot. Gross Weight is the weight of the ingot after it has been scalped. The objective is to maximize the recovery number.

have to deal with less inventory because the customer will take the majority of the metal. As far as what should be done now, I suggest having the customer order on the lower side of the distribution rather than the higher side because the customer should not suffer from problems that are internal to AMP. Once ingot yield is more stable, AMP can move towards having the customer order in greater quantities.

To help drive the focus onto quality recovery, I would recommend the implementation of a new performance metric, Yield Variability, at Davenport Works in conjunction with Recovery. While maximizing recovery makes sense and should not be abandoned, the pursuit of recovery should not ignore production yield variability. By implementing both measures of performance, managers will be given incentives to attack the root cause problems of quality recovery, the primary source of production yield variability. This will result in a situation where recovery will be maximized and production yield variability will be minimized.

### 6.1.2: Reduce the Number of Ingot Sizes

Production yield variability exists within Davenport Works and the root cause problems responsible for this variability are largely unknown. In addition, there are numerous ingot sizes to choose from (185 different planned ingots for sheet and 113 different planned ingots for plate) when production is initiated. The proliferation of ingot sizes (to increments of three inches in length) seemed to evolve due to an effort to increase recovery (engineered recovery). However, the true benefits from this practice can only be realized if production yields are stable. If your production yields are variable in terms of hundreds of pounds you may or may not realize the benefits of initiating production with an ingot that was only three inches shorter.

I would recommend significantly reducing the number of ingot sizes (perhaps 3-5 sizes differentiated as small, small-medium, medium, medium-large, and large). This may have several potential benefits:

- Reducing the number of ingot specifications will greatly simplify the ingot casting schedules which may help reduce replenishment lead-time (currently approximately 2 weeks is reserved for ingot scheduling in our total replenishment lead-time). In addition, by significantly reducing the number of ingot specifications, the level of ingot inventory on the ingot pad can also be significantly reduced. This would result in inventory cost savings as well as increasing the probability that the type of ingot needed for production would actually be in stock (which would also help reduce the replenishment lead time).

- One hypothesis is that by continually casting the same sizes of ingots there may be some repeatability benefits that can be realized. The quality of ingot casting may improve and set-up times for ingot casting may decrease. Since there are several occasions where casting may be the cause of significant quality recovery problems (i.e., when a lot is 100% scrapped due to ultrasonic defects), improvements in casting may positively impact production yield variability (especially in terms of ultrasonic defects).
- Another hypothesis is that continually working with the same size ingot may have positive benefits in terms of quality recovery within our production processes. Improvements due to the benefits of repeatability may help reduce some of the variability in the system.

### 6.1.3: Investigate Ways to Satisfy Smaller Orders on a JIT Basis

Many business organizations are focusing on reducing costs and streamlining both their organizational structures and operational processes. Customers will be increasingly demanding what they want in the quantities that they want, when they want it. For AMP, this translates into increased quality, smaller order quantities and reduced lead-times. Although AMP's customers seem to be moving in the direction of smaller order quantities (only ordering what they need), AMP seems to be moving in the direction of maximizing recovery and forcing the customer to take the recovery of an ingot (whatever that may be). I think AMP needs to ask itself, how they want to operate their business.

1. Try to maximize the efficiencies of their processes and then essentially force the customer to accept the end results.

2. Try to develop a thorough understanding of their customers and their requirements as a starting point, and then develop a system to best meet those requirements.

Now this needs to be kept in perspective. The customer wants exact quantities right now for free and that is unrealistic. However, I think in the future there will be more customers like "Customer A" rather than less; and if AMP cannot provide what the customer wants, the customer will eventually take their business elsewhere.

### 6.1.4: Reserve Capacity for Key Customers and use the OBT for Spot Business

To address capacity constrained lead-time, I would recommend reserving capacity in the system for key customers and utilizing the OBT for only spot business. Blocking off capacity in the system for key customers could do this. The OBT would still provide a promise date for the key customers but production would never be delayed due to the plant being overbooked. For non-key customers, the OBT would be used as it has always been used but the amount of capacity they will be fighting for will be significantly smaller (since a large fraction will be allocated to the key customers). Implementing this practice will have two primary benefits. Firstly, it eliminates a significant amount of lead-time variability in our process when Davenport Works is running close to capacity. Lead time variability within a designated flowpath is something that can be measured, identified, and worked on. However, lead time variability as a result of increased customer orders is much more difficult to anticipate and is beyond AMP's control to eliminate based on how the current capacity reservation system operates. Secondly, it would protect our major customers by ensuring that they have the capacity that was promised to them (through the customer agreement) available in system.

In addition, I would recommend examining the discrepancies between the mill flowtimes based on the data analysis and the mill flowtimes that are actually perceived and quoted within AMP. The discrepancies should be understood and eliminated to facilitate more efficient operations and accurate planning based on realistic lead times. Furthermore, understand that flowtimes are different for different products. Since one "general" replenishment lead-time is usually quoted for a customer (or one for plate and one for sheet), this has the potential to impact both delivery performance and inventory requirements.

## 6.2: European Sales Office

### 6.2.1: Create Standards of Work and Ensure that Established Policies are Adhered To

There are several issues involving the creation of standards of work at the European sales office and ensuring that established policies are adhered to. Firstly, the inputting of customer orders into the European Oracle information system is critical to determine customer demand (magnitude and variability) for different products over time. They have established a system that if followed correctly, ensures there is no potential to double count or exclude a particular order delivered to the customer. However, there may be some differences in how orders are entered into the system based on the individual practices of the CSR's. The European sales office must ensure that the established policies on order entry and processing are well communicated, understood, and adhered to.

Secondly, trade offs concerning supply chain variables and customer requirements need to be evaluated before customer contracts are established. Furthermore, once the customer contract is established, the guidelines stated in the contract should be adhered to. If you develop customer contracts by balancing the trade offs between supply chain capabilities and customer requirements, and then do not adhere to the established guidelines of the contract, there is a high potential for problems. The customer contract with "Customer A" is an excellent example. The capabilities of the supply chain were not balanced against customer requirements, and the guidelines established in the contract are completely ignored by both parties. As a result, "Customer A" is causing several problems within the AMP supply chain.

### 6.2.2: Work on Reducing Demand Variability

The customer's needs dictate their demand so it is impossible to determine a particular customer's demand with 100% certainty. However, by working with the customer to gain a better understanding of their requirements and then collaborating with the customer to develop ordering policies, mutual benefits can be achieved. This will also help AMP develop a better understanding of the root causes of the demand variability so they can be addressed. This requires customer relationships built on trust and takes significant time and effort. As a result, this cannot be done with all customers but I would recommend building collaborative relationships with key customers focusing on reducing unpredictable demand variability.

## 6.3: Alcoa International Service Center (AISC) in Europe

### 6.3.1: Explore Ways to Increase the Utilization of the AISC's Capabilities to Increase Supply Chain Flexibility

The AISC has significant processing capabilities that are not being utilized to their full extent. While all the products for European customers cannot be processed on the equipment at the AISC due to product dimensions, there are a significant percentage of products that can. Currently, there is a tremendous amount of excess capacity on the equipment within the AISC. Use of this capacity within AISC will enable the limited capacity at Davenport Works to be applied to other businesses.

AISC has proven that they can effectively process metal as evidenced by the cut-to-size program with "Customer C". I would recommend expanding the concept of the cut-to-size program to other customers. This would increase the flexibility AMP could provide to the customer as well as alleviate some of the manufacturing burden on Davenport Works. However, I would recommend the expansion be done incrementally to ensure both the administrative systems and the processing systems are scaled up accordingly to handle the increased amount of work.

## 6.4: Overall Supply Chain

### 6.4.1: Problem Definition for Supply Chains

The process for developing an understanding of root cause problems, especially when they are extremely complex and span across different organizations, takes time and is essential before effective, long-lasting solutions can be implemented. In today's fast paced, results oriented business environment, the need for action is a driving force in many managers' behavior. As a result, less time is often spent on developing a solid understanding of why problems exist and more time is spent on initiating action to solve perceived problems. The development of a detailed problem definition is extremely important before resources are deployed to attack a perceived problem. If the correct problem is not accurately identified, time and resources may be wasted. Furthermore, if the problem you are solving is only a symptom of the root cause problem; then eventually other problems will manifest themselves.

In addition, the process of developing an understanding of root cause problems requires systems thinking and an ability to approach the situation from a holistic viewpoint. This requirement is especially important when dealing with the complex problems associated with supply chains. Due to the broad scope across which the AMP supply chain impacts, one needs to think about the supply chain issues from a holistic viewpoint and it is difficult to identify supply chain problems when your perspective is limited by the boundaries of your particular stage in the supply chain. Specifically, supply chain problems need to be examined from a systems (or in this case business unit) perspective rather than solely from the perspective of any one stage of the supply chain.

### 6.4.2: Establish the Necessary Information Systems

An information system that can operate seamlessly across the different organizations within the AMP supply chain does not exist and would be useful. The Davenport Works IT system facilitates efficient information flow within Davenport Works (despite the fact that it is a conglomeration of legacy systems) and the new Oracle information system in Europe facilitates efficient information flow between the European sales office and the AISC in Europe, but these two systems cannot currently facilitate the efficient flow of information between them. In order to apply the base stock model (or effectively manage your inventory in another way), inputs need to be gathered from Davenport, the European sales office, the European warehouse, and the customer. Currently there are no established procedures so that one person, in one location can gather all this information. This situation leads to inconsistencies in measuring performance, inconsistencies in the actual data, and makes cross-organizational communications more difficult.

Data collection plays a major role in systems analysis. There are significant amounts of variability across the AMP supply chain yet, the information systems are not being utilized to collect and analyze data concerning variability. Averages are generally utilized when distributions may be more appropriate. To understand the impact of variability on supply chain performance, the data on variability needs to be collected and analyzed in an efficient manner. Currently this is difficult to do in a timely manner and often involves some manual manipulations of the data.

There are also challenges concerning the utilization of a form of the base stock inventory model to manage inventories within AMP. The base stock model is applied on a product by product basis. To be effectively applied to all customers in Europe (and potentially all global customers), software needs to be developed to efficiently gather the inputs, perform the calculations, and consolidate the outputs.

### 6.4.3: Share Supply Chain Knowledge Across the Supply Chain

A supply chain is a system comprised of four general stages: the order generation and order processing stage; the manufacturing stage; the logistics stage; and the customer service. In order for a system to perform optimally, actions among supply chain entities must contribute to the overall system performance. If you don't understand the supply chain system, it is difficult to tailor actions to improve the overall system performance.

I strongly recommend that knowledge of the supply chain system be shared and understood across each of the entities that make up the supply chain system. At the very least this should be done for entities that are part of the AMP organization. This is particularly important since no one individual has 100% visibility of the entire AMP supply chain. A shared understanding of the AMP supply chain system will promote systems thinking and ensure that all supply chain issues are identified and dealt with in a prudent way that benefits the entire supply chain rather than local optimization within a specific supply chain segment. In addition, familiarization with the entire supply chain system will facilitate “out of the box” thinking that expands beyond traditional organizational silos, as well as improve communications across the different organizations within AMP.

Works Consulted

Black, Brian E. LFM Masters Thesis: Utilizing the Principles and Implications of the Base Stock Model to Improve Supply Chain Performance. MIT Sloan School of Management, MIT Department of Electrical Engineering and Computer Science, 1998.

Davis, Tom. "Effective supply chain management." Sloan Management Review 34.4 (Summer 1993): 35-46. http://gateway.ovid.com/server1/ovidweb...21&totalCit=732&D=info&S=IDNJHKDKDCAANK.

Graban, Mark R. LFM Masters Thesis: An Inventory Planning Methodology for a Semiconductor Manufacturer with Significant Sources of Variability. MIT Sloan School of Management, MIT Department of Mechanical Engineering, 1999.

Graves, Stephen C. Lecture notes for Operations Management Models and Applications (15.762). MIT. Spring 1999.

Hopp, Wallace J., and Mark L. Spearman. Factory Physics-Foundations of Manufacturing Management. Boston: Irwin McGraw-Hill, 1996.

Inman, Robert R. "Inventory is the flower of all evil." Production & Inventory Management Journal 34.4 (4Q 1993): 41-45. http://gateway.ovid.com/server1/ovidweb...&R=1&totalCit=1&D=info&S=IDNJHKEKPCLDMK.

LaLonde, Bernard J., and James M. Masters. "Emerging logistics strategies: Blueprints for the next century." International Journal of Physical Distribution & Logistics Management 24.7 (1994): 35-47. http://gateway.ovid.com/server1/ovidweb...80&totalCit=732&D=info&S=IDNJHKDKDCAANK.

Lambert, Douglas M., James R. Stock and Lisa M. Ellram. Fundamentals of Logistics Management. Boston: Irwin McGraw-Hill, 1998.

Larson, Paul D., and Dale S. Rogers. "Supply chain management: Definition, growth and approaches." Journal of Marketing Theory & Practice 6.4 (Fall 1998):1-5. http://gateway.ovid.com/server1/ovidweb...49&totalCit=732&D=info&S=IDNJHKDKDCAANK.

Layden, John. "Thoughts on supply-chain management." Manufacturing Systems 16.3 (March 1998): 80-88. http://gateway.ovid.com/server1/ovidweb...86&totalCit=732&D=info&S=IDNJHKDKDCAANK.

Lee, Hau L., and Corey Billington. "Managing Supply chain Inventory: Pitfalls and Opportunities." Sloan Management Review 33.3 (Spring 1992): 65-73. http://gateway.ovid.com/server1/ovidweb...29&totalCit=732&D=info&S=IDNJHKDKDCAANK.

Masters, James. Class lecture notes for Logistics Systems (1.260). MIT. Fall 1998.

Miller, Michael P. LFM Masters Thesis: Business System Improvements Through Recognition of Process Variability. MIT Sloan School of Management, MIT Department of Chemical Engineering, 1997.

Nahmias, Steven. Production and Operations Analysis. Third Edition. Chicago: Irwin, 1997.

Quinn, Francis J. "Building a world-class supply chain." Logistics Management & Distribution Report 37.6 (June 1998): 38-44. http://gateway.ovid.com/server1/ovidweb...43&totalCit=732&D=info&S=IDNJHKDKDCAANK

# APPENDIX A: Brian Black's Extension of the Base Stock Model to Account for Production Yield Variability[56]

Brian Black (LFM 1998) developed an extension for the original base stock model to account for production yield variability during his internship with the Eastman Kodak Company's Kodak Equipment Manufacturing Division (KEMD). This appendix will provide a general overview of the extension to the base stock model for production yield variability and present the equations developed by Brian Black.

The base stock model attempts to balance probable supply with probable demand over the replenishment lead time to minimize stockouts and maximize customer service levels. Demand over the replenishment lead time can be characterized by the following equations:

| | | |
|---|---|---|
| Expected (Demand) = $\mu_D * (r + L)$ | Variance (Demand) = $\sigma_D^2 * (r + L)$ | **(1)** |

Supply is the combination of WIP inventory plus FGI. Since production yields are variable, supply is uncertain. We assume that production is done in lots and each lot represents one ingot's worth of production. We can characterize the production yield from an ingot to have a mean ($\mu_S$) and a standard deviation ($\sigma_S$). In-process supply over the replenishment lead time can be characterized by the following equations:

| | | |
|---|---|---|
| Expected (WIP) = $\mu_S * I$ | Variance (WIP) = $\sigma_S^2 * I$ | **(2)** |
| Where I equals the number of ingots in production. | | |

To determine the supply over the replenishment lead time we must also include the current FGI. Therefore, supply over the replenishment lead time can be characterized by the following equations:

[56] The information in this appendix was taken from Brian Black's (LFM 1998) thesis, "Utilizing the Principles of the Base Stock Model to Improve Supply Chain Performance", 26-28.

$$\text{Expected (Supply)} = (\mu_S * I) + FGI \qquad \text{Variance (Supply)} = \sigma_S^2 * I \qquad \textbf{(3)}$$

We assume that supply and demand can be modeled as independent random variables. Then we can combine equations (1) and (3) to characterize Supply – Demand:

$$\text{Expected (Supply – Demand)} = (\mu_S * I) + FGI - \mu_D * (r + L)$$

$$\text{Variance (Supply – Demand)} = \sigma_S^2 * I + \sigma_D^2 * (r + L) \qquad \textbf{(4)}$$

In order to ensure that the supply over the replenishment lead time exceeds the demand over the replenishment lead time, the following equation must hold:

$$[(\mu_S * I) + FGI - \mu_D * (r + L)] - (z) * SQRT[\sigma_S^2 * I + \sigma_D^2 * (r + L)] >= 0 \qquad \textbf{(5)}$$

In this equation z denotes the safety factor for a specified probability that supply will be greater than demand.

This equation can be solved to determine the number of ingots (I) that need to be WIP to achieve a desired customer service level or it can be solved for (z) to determine the expected customer service level given the inputs from the supply chain.

# APPENDIX B: Mark Graban's Extension of the Base Stock Model to Account for Lead Time Variability[57]

Mark Graban (LFM 1999) built on Brian Black's work with the base stock model and made an additional extension to the base stock model to account for lead time variability. Graban developed his extension while working on his internship with the Eastman Kodak Company's Microelectronics Technology Division (MTD). This appendix will provide a general overview of the extension to the base stock model for lead time variability and present the equations developed by Mark Graban.

Graban utilized Black's Base Stock Model for Production Yield Variability equation as the start point for his extension.

$$[(\mu_S * I) + FGI - \mu_D * (r + L)] - (z) * SQRT[\sigma_S^2 * I + \sigma_D^2 * (r + L)] >= 0$$

In this equation z denotes the safety factor for a specified probability that supply will be greater than demand.

It was assumed that the replenishment lead time is normally distributed (independent and identically distributed). If there is variability associated with the replenishment lead time, then the expected demand must be represented as a function of the average replenishment lead time ($\mu_{LT}$) and the variance of replenishment lead time ($\sigma_{LT}^2$). Therefore, to account for replenishment lead time variability, the term utilized for demand variability must be changed:

| | |
|---|---|
| Demand Variability Term in Black's Extension: | $SQRT[\sigma_D^2 * (r + L)]$ |
| Demand Variablity Term in Graban's Extension: | $SQRT[\sigma_D^2 * (r + \mu_{LT}) + \mu_D^2 * \sigma_{LT}^2]$ |

By substituting the revised demand variability term into the equation developed by Black, we arrive at the following equation to account for replenishment lead time variability:

[57] The information in this appendix was taken from Mark Graban's (LFM 1999) thesis, "An Inventory Planning Methodology for a Semiconductor Manufacturer with Significant Sources of Variability", 44-45.

$$[(\mu_S * I) + FGI - \mu_D * (r + L)] - (z) * SQRT[\sigma_S^2 * I + \sigma_D^2 * (r + \mu_{LT}) + \mu_D^2 * \sigma_{LT}^2] >= 0$$

In this equation z denotes the safety factor for a specified probability that supply will be greater than demand.

Like Black's extension, this equation can be solved to determine the number of ingots (I) that need to be WIP to achieve a desired customer service level or it can be solved for (z) to determine the expected customer service level given the inputs from the supply chain.

# APPENDIX C: Calculations for the Base Stock Model Application for a "A Item"

Spreadsheet Data For A Item Example

| Start of Month | Demand | Order Quantity (Q) | Ingot Impact (D-Q) | Excess Pounds On Hand | FGI into AISC | Safety Stock | Cycle Stock | WIP | Total Inventory |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 9,525 | 64,570 | 0 | 74,095 |
| 1 | 9,707 | 15,240 | 5,533 | 5,533 | 0 | 9,525 | 55,229 | 15,240 | 79,994 |
| 2 | 11,649 | 7,620 | -4,029 | 1,504 | 0 | 9,525 | 43,580 | 22,860 | 75,965 |
| 3 | 15,531 | 15,240 | -291 | 1,213 | 0 | 9,525 | 28,049 | 38,100 | 75,674 |
| 4 | 13,197 | 15,240 | 2,043 | 3,256 | 0 | 9,525 | 14,852 | 53,340 | 77,717 |
| 5 | 13,593 | 15,240 | 1,647 | 4,903 | 15,240 | 9,525 | 16,499 | 53,340 | 79,364 |
| 6 | 15,626 | 15,240 | -386 | 4,517 | 7,620 | 9,525 | 8,493 | 60,960 | 78,978 |
| 7 | 9,707 | 7,620 | -2,087 | 2,430 | 15,240 | 9,525 | 14,026 | 53,340 | 76,891 |
| 8 | 11,649 | 15,240 | 3,591 | 6,021 | 15,240 | 9,525 | 17,617 | 53,340 | 80,482 |
| 9 | 15,531 | 15,240 | -291 | 5,730 | 15,240 | 9,525 | 17,326 | 53,340 | 80,191 |
| 10 | 13,197 | 7,620 | -5,577 | 153 | 15,240 | 9,525 | 19,369 | 45,720 | 74,614 |
| 11 | 13,593 | 15,240 | 1,647 | 1,800 | 7,620 | 9,525 | 13,396 | 53,340 | 76,261 |
| 12 | 15,626 | 15,240 | -386 | 1,414 | 15,240 | 9,525 | 13,010 | 53,340 | 75,875 |
| 13 | | | | | 15,240 | | | | |
| 14 | | | | | 7,620 | | | | |

Notes:

1. Values are in pounds (with the exception of Month).

2. The analysis assumes that all base stock inventory is in FGI at time zero.

3. Demand = The customer demand from the beginning of the preceding month to the start of the current month. (i.e. demand at start of Month One equals the demand from time zero to the beginning of month 1)

4. During Month 6 it was necessary to dip into the safety stock by approximately 1214 pounds. During month 11 it was necessary to dip into the safety stock by approximately 2230 pounds.

# APPENDIX D: Calculations for the Base Stock Model Application for a "C Item"

Spreadsheet Data For C Item Example

| Start of Month | Demand | Order Quantity (Q) | Ingot Impact (D-Q) | Excess Pounds On Hand | FGI Into AISC | Safety Stock | Cycle Stock | WIP | Total Inventory |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 1,726 | 945 | 0 | 0 |
| 1 | 0 | 0 | 3,004 | 3,004 | 0 | 1,726 | 945 | 0 | 2,671 |
| 2 | 1,146 | 4,150 | 0 | 3,004 | 0 | 1,525 | 0 | 4,150 | 5,675 |
| 3 | 0 | 0 | 0 | 3,004 | 0 | 1,525 | 0 | 4,150 | 5,675 |
| 4 | 0 | 0 | 0 | 3,004 | 0 | 1,525 | 0 | 4,150 | 5,675 |
| 5 | 0 | 0 | 0 | 3,004 | 0 | 1,525 | 0 | 4,150 | 5,675 |
| 6 | 0 | 0 | 0 | 3,004 | 4,150 | 1,726 | 3,949 | 0 | 5,675 |
| 7 | 0 | 0 | 0 | 3,004 | 0 | 1,726 | 3,949 | 0 | 5,675 |
| 8 | 1,146 | 0 | -1,146 | 1,858 | 0 | 1,726 | 2,803 | 0 | 4,529 |
| 9 | 0 | 0 | 0 | 1,858 | 0 | 1,726 | 2,803 | 0 | 4,529 |
| 10 | 0 | 0 | 0 | 1,858 | 0 | 1,726 | 2,803 | 0 | 4,529 |
| 11 | 0 | 0 | 0 | 1,858 | 0 | 1,726 | 2,803 | 0 | 4,529 |
| 12 | 0 | 0 | 0 | 1,858 | 0 | 1,726 | 2,803 | 0 | 4,529 |
| 13 | | | | | 0 | | | | |
| 14 | | | | | 0 | | | | |

Notes:

1. Values are in pounds (with the exception of Month).

2. The analysis assumes that all base stock inventory is in FGI at time zero.

3. Demand = The customer demand from the beginning of the preceding month to the start of the current month. (i.e., demand at start of Month One equals the demand from time zero to the beginning of month 1)

4. During Month 2 it was necessary to dip into the safety stock by approximately 201 pounds. The Safety Stock was not replenished until Month 6.