Raw Material Inventory Planning in a Serial System with Warehouse Capacity

by

Jason Jinho Choi

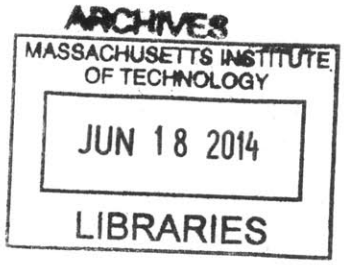
B.S. Engineering, Harvey Mudd College, 2004
M.S. Mechanical Engineering, University of Southern California, 2010

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

Master of Business Administration
and
Master of Science in Engineering Systems

In conjunction with the Leaders for Global Operations Program at the Massachusetts Institute of Technology

June 2014



Signature of Author Signature redacted
Engineering Systems Division, MIT Sloan School of Management
May 9, 2014

Certified by Signature redacted
Donald Rosenfield, Thesis Supervisor
Senior Lecturer, MIT Sloan School of Management

Certified by Signature redacted
Bruce Cameron, Thesis Supervisor
Lecturer, Engineering Systems Division

Accepted by Signature redacted
Maura Herson
Director of MIT Sloan MBA Program
MIT Sloan School of Management

Accepted by Signature redacted
Richard C. Larson
Mitsui Professor of Engineering Systems
Chair, Engineering Systems Division Education Committee

This page intentionally left blank

Raw Material Inventory Planning in a Serial System with Warehouse Capacity

Abstract by

Jason Jinho Choi

Submitted to the MIT Sloan School of Management and the Engineering Systems Division on May 9, 2014 in Partial Fulfillment of the Requirements for the Degrees of Master of Business Administration and Master of Science in Engineering Systems

Abstract

The thesis explores inventory management principles in the context of a storage capacity constrained warehouse.

Amgen Inc. is building a new manufacturing facility in Singapore. Due to internal raw material warehouse capacity constraints, Amgen is evaluating the use of a 3rd Party Logistics (3PL) for additional warehousing space. The goal of this project is to recommend a raw material inventory strategy to reduce inventory levels and a 3PL operation guideline to ensure the availability of storage space and to minimize the transfers of raw material between Amgen and the 3PL.

The project developed four inventory management methodologies to reduce raw material inventory in the context of a warehouse with a capacity constraint:

1. Batch size optimization with an extension of the economic order quantity (EOQ) that adjusts batch size based on available warehouse space.
2. Safety stock reduction with the removal of demand variability by fixing the production schedule for 6 months. This results in a 10% inventory reduction by value and an 18% reduction in warehouse space usage.
3. Vendor managed inventory (VMI) with suppliers in Singapore to reduce inventory by 5%.
4. Maintaining commonality of disposable raw materials at 75% for new products that use the Manufacturing of the Future (MoF) platform to mitigate a 46% increase in room temperature warehouse space.

As Amgen starts to use a 3PL, we recommend:

1. Use the 3PL in series with Amgen's warehouse to minimize raw material transfers.
2. Use the created warehouse model for 3PL operation guidelines. The model calculates the raw material requirements for a given production plan and recommends how to route the raw material and computes the space required for Amgen and the 3PL.
3. Use recommended key performance indicators to ensure data input into the warehouse model is accurate for correctly optimized results.

Thesis Supervisor: Donald Rosenfield, Senior Lecturer, MIT Sloan School of Management
Thesis Supervisor: Bruce Cameron, Lecturer, Engineering Systems Division

This page intentionally left blank

Acknowledgements

I wish to acknowledge the Leaders for Global Operations Program and Amgen, Inc. for their support of this work.

Special thanks go to Jared Bryne for making this project possible and for taking considerable time to guide me through the biotechnology industry. I would like to also thank Kris Lee who always had the time to give me feedback that greatly contributed to this work.

I would like to recognize both of my thesis advisors, Don Rosenfield and Bruce Cameron who supported me throughout my internship.

I am grateful for the support from my parents. I would not have made it so far without your love. You always believed in me and supported me through my many years of education, for which I am eternally grateful.

Lastly and most importantly, I would like to thank my wife SungHee for the love and encouragement through all the work.

This page intentionally left blank

Note on Proprietary Information

In order to protect proprietary Amgen information, the data presented throughout this thesis have been altered and do not represent the actual values used by Amgen, Inc. Recommendations are purposefully presented in percentages to conceal dollar values and warehouse information.

This page intentionally left blank

Table of Contents

List of Figures

List of Tables

This page intentionally left blank

1. Introduction

The information presented in this thesis explores inventory management principles in the context of a storage capacity constrained supply chain and is the result of an internship with Amgen, Inc. from May to December 2014. Amgen's Manufacturing of the Future (MoF) organization sponsored the internship to assess the raw material inventory management plan for a new manufacturing facility in Singapore.

1.1. Project Motivation

Amgen is a global biotechnology company that manufacturers medicines for cancer, kidney disease, rheumatoid arthritis, bone disease, and other serious illnesses. Amgen is building a $200M state-of-the-art manufacturing facility in Singapore expected to complete in 2015.[1] Within the facility is a raw material warehouse that will store ingredients such as chemicals, media, filters and tubes. An analysis shows that as the new facility's manufacturing ramps up, the internal raw material warehouse will become capacitated, as seen in Figure 1.

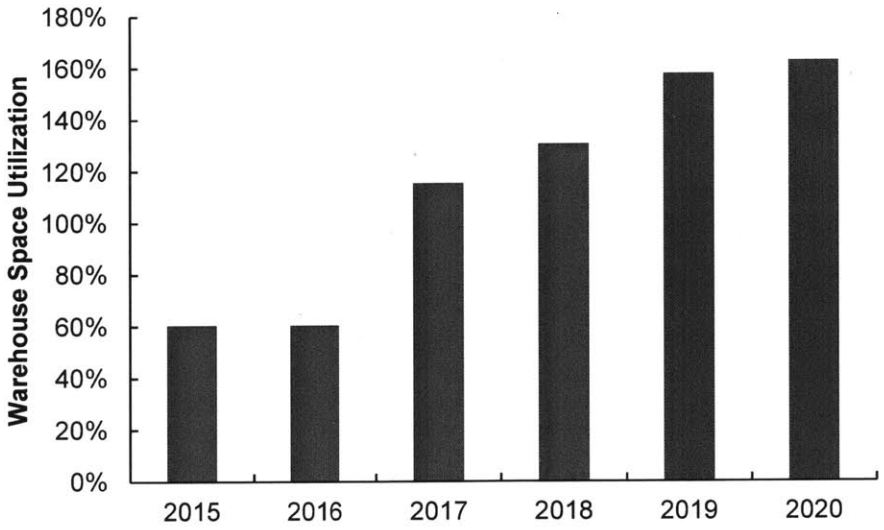


Figure 1 Amgen Warehouse Projected Utilization

The cost of capacitating the warehouse is high with the potential for loss of raw material through spoilage and manufacturing disruption. Thus, Amgen is considering the use of a 3rd Party Logistics (3PL) as an additional raw material warehouse in Singapore. A 3PL is a firm that provides supply chain and logistic

[1] "Amgen To Build State-Of-The-Art Manufacturing Facility In Singapore -- THOUSAND OAKS, Calif., Jan. 16, 2013 /PRNewswire/ --."

services. The 3PL will charge Amgen by the number of pallets stored per unit time. The goal is to remove or reduce the 3PL usage by reducing inventory and to develop a 3PL operations plan.

1.2. Problem Statement

The purpose of this thesis is twofold. First is to review several inventory management strategies to reduce raw material inventory in the context of biotechnology drug substance manufacturing. Second is to develop a warehouse model that will set the guidelines to route raw material between the 3PL and Amgen's warehouse. The warehouse model should be flexible and easy to use for the Site Supply Chain Manager to easily update and implement in Singapore.

1.3. Research Methodology

The author spent six months on site at Amgen, Inc., in Thousand Oaks, CA. Because of the relatively compressed time frame, the research is not intended to be a comprehensive body of all possible solutions to reduce inventory or to effectively use a 3PL. Rather it is intended to represent several case studies that were considered for implementation when the Singapore facility goes live.

A three step approach is taken in the research, 1) current state data gathering, 2) research and analysis, and 3) future state recommendations as shown in Figure 2.

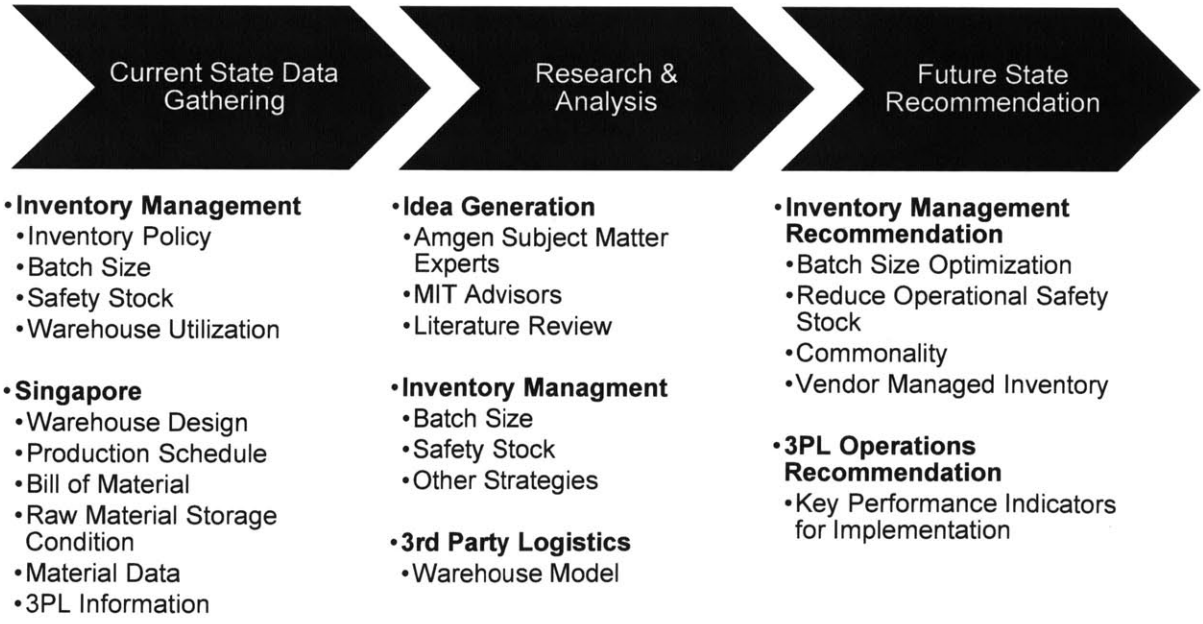


Figure 2 Research Methodology

In the current state data gathering phase, we collect information about Amgen's inventory management practices and the plans for the Singapore site. In the research & analysis phase, we generate inventory methods that is effective in dealing with a capacity constrained system and develop tools to quantify the benefits of the methods. In the future state recommendation phase, we create implementation recommendations for the Singapore management.

1.4. Thesis Overview

This thesis is segregated by chapters following the research methodology. The contents of each can be briefly described as follows:

Chapter 2 is a literature review on topics relevant to our research. This includes a review on inventory management practices and 3rd Party Logistics. Under inventory management practices, we will discuss ABC classification, inventory policies, batch sizing, safety stock, commonality and vendor managed inventory.

Chapter 3 provides a background of the partner company, Amgen Inc. in the context of this research. This includes information on the new manufacturing site in Singapore, an overview of biotechnology manufacturing and background on biotechnology raw materials.

Chapter 4 discusses the current state analysis of Amgen's inventory management practices and the planned raw material warehouse in Singapore. Amgen's inventory management practices will include information on Amgen's inventory policy, batch size and safety stock setting methodologies. This will also include an introduction to the difference between raw materials for clinical manufacturing and commercial manufacturing.

Chapter 5 discusses the methodology and analysis to control raw material inventory and to manage 3PL inventory. This includes an analysis and potential savings from reducing safety stock, optimizing batch size, maintaining commonality and introducing vendor managed inventory in Singapore. We will review the concept of using the 3PL in parallel and in series with Amgen's internal warehouse. Lastly, we will identify key performance indicators for implementing a 3PL using the inventory allocation model.

Chapter 6 provides our conclusions from our research. We will first review our recommendations and offer opportunities for future research.

2. Literature Review

The intent of this chapter is to review literature that guided our methodology to improve the current inventory management practices and recommend a method to use a 3PL. We first discuss inventory management practices that have a potential for decreasing inventory and then discuss literature on 3rd Party Logistics.

2.1. Inventory Management

Increased competition in the global markets, changing customer demand, and shorter product lifecycles have forced businesses to focus on their supply chain. In many industries, inventory is one of the dominant costs. "In the United States, for example, over a trillion dollars is invested in inventory."[2] Inventory management is a large area for improvement in many companies with many cases where improved inventory management can lead to cost savings of at least 20 percent, without sacrificing customer service.[3]

Though, inventory can appear as three different types of inventory: raw material inventory, work in process (WIP) inventory and as fished product inventory, this research concentrates on the raw material inventory. In the subsequent sections, we present methods to manage this raw material inventory by setting batch size and safety stock and then introduce the concepts of commonality and vendor managed inventory. The following are effective in dealing with capacity constrained systems as well as non-capacity constrained systems.

2.1.1. ABC Classification

Managing an inventory effectively starts with understanding the characteristics of the SKUs such as the SKU demand, lead times and value. A SKU is a stock keeping unit and can also be defined as the different items of stock. A SKU grouping that is prominently used in several industries is the ABC Classification method. The ABC Classification helps identify the SKU that are the most important by cost. Though the classification methodology may be slightly different from company to company the general rule is that:[4]

- A items make up roughly 20 percent of the total number of items and 80 percent of the value.
- B items make up roughly 30 percent of the total number of items and 15 percent of the value.

---

[2] Simchi-Levi, Kaminsky, and Simchi-Levi, *Designing and Managing the Supply Chain.*
[3] Silver et al., *Inventory Management and Production Planning and Scheduling.*
[4] Ibid.

- C items make up roughly 50 percent of the total number of items and 5 percent of the value.

The ABC Classification is illustrated in Figure 3 with the 'total number of SKU' on the x-axis and the 'total annual dollar volume' on the y-axis.

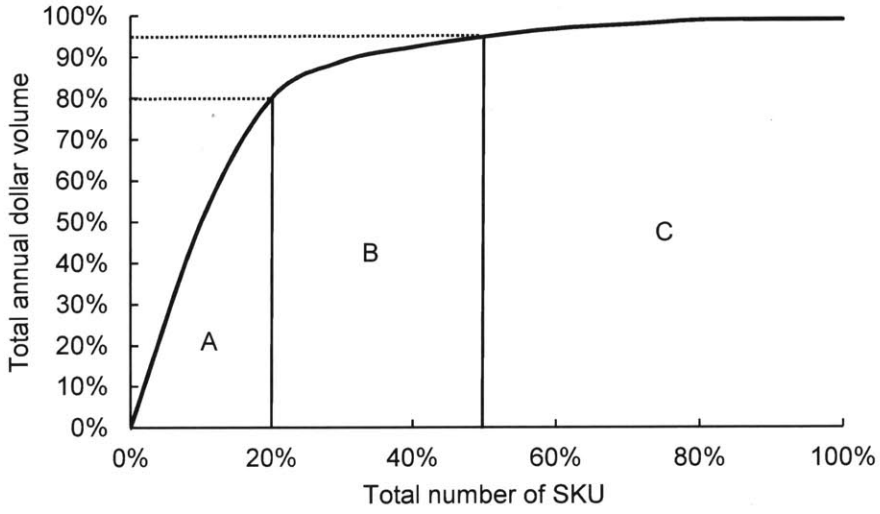


Figure 3 Distribution by Value of SKUs

In the ABC Classification, A items are most important, B items are intermediate in importance and C items are least important. In terms of inventory management then, A items should be managed closely potentially with a customized inventory policy. In section 4.1.3, we discuss how Amgen uses the ABC Classification to set the batch size.

2.1.2. Inventory Policy

Once the A, B, or C category has been determined, the inventory policy determines how often a SKU should be reordered and how large the order should be. There are several different forms of inventory policies but can largely be divided into two categories based on how frequently the inventory level is evaluated. The two categories are continuous review policies and periodic review policies. As each name implies, a continuous review policy requires a continuous review of the inventory levels whereas a periodic review policy only requires the inventory level to be determined every R time units.

Continuous review policies can provide the same level of customer service with smaller safety stock which allows for lower inventory holding cost. This is because the period over which safety stock must protect is longer for periodic review policies. However, periodic review policies are considered easier and more economical to implement because it simplifies replenishment with a regular schedule and does not require a potentially costly computer control system or processes for continuous inventory tracking.

Further, periodic review policies can be preferred in situations where there are benefits from coordinating regular replenishments from the supplier. "For example, when ordering from overseas, it is often necessary to fill a shipping container to keep shipping costs under control. The coordination afforded by a periodic review system can provide significant savings."[5]

Four inventory policies are described below:

1. *Order-Point, Order-Quantity (s, Q)* is a continuous review policy. A fixed order quantity or batch size Q is ordered whenever the inventory position drops below a fixed quantity, s.
2. *Order-Point, Order-Up-to-Level (s, S)* is a continuous review policy. SKUs are ordered to raise the inventory position up to level S whenever the inventory drops below a fixed quantities, s.
3. *Periodic-Review, Order-Up-To-Level (R, S)* is a periodic review policy. SKUs are ordered to raise the inventory position up to level S at each time period R.
4. *(R, s, S)* is a periodic review policy. The inventory is checked at each time period R units. If the inventory below a fixed quantity s, the item is ordered to raise the inventory position up to level S.

Table 1 show the pros and cons of each of the inventory policies.

Inventory Policy	Pros	Cons
Order-Point, Order-Quantity (s, Q)	Simple to understand and implement	Inflexible for one-time events
Order-Point, Order-Up-to-Level (s, S)	Lower costs than (s, Q)	More computational effort needed to find optimal (s, S) pair than (s, Q)
Periodic-Review, Order-Up-To-Level (R, S)	A periodic review is easier to implement than a continuous review policy	Inventory holding costs are higher than in continuous review policies
(R, s, S)	Can potentially offer the lowest cost	Most computationally intense

Table 1 Pros & Cons of Inventory Policies

2.1.3. Batch Size

The batch size refers to the order or replenishment quantity and is the Q in the (s, Q) inventory policy explained in the previous section. Though there are many considerations in setting the batch size, in this section we will discuss how the characteristics of demand affect batch size. There are three potential

[5] Ibid.

methods to set raw material batch size based on the behavior of demand: 1) when demand is approximately level, 2) when demand varies with time, and 3) when demand is probabilistic.

For Amgen, the raw material demand varies with time but is mainly deterministic where the uncertainty is dealt with by safety stock. So we concentrate on the method to set the batch size for a deterministic time-varying demand. For this case, there are three approaches to setting the batch size,[6]

1. *Use of the basic economic order quantity or EOQ.* The EOQ is the order quantity that minimizes total inventory holding cost and ordering cost. This is a simple approach and is not the most always optimal because the underlying assumption of the EOQ is that the demand rate is constant. Thus this approach is most appropriate when the variability in demand is low. EOQ is defined by the following equation,

$$EOQ = \sqrt{\frac{2AD}{vr}}$$

$$A = fixed\ ordering\ cost\ (\$/order)$$

$$D = average\ demand$$

$$v = purchase\ cost\ (\$/unit)$$

$$r = holding\ cost\ (\$/\$/time)$$

Figure 4 illustrates how using the EOQ can minimize total cost.

[6] Ibid.

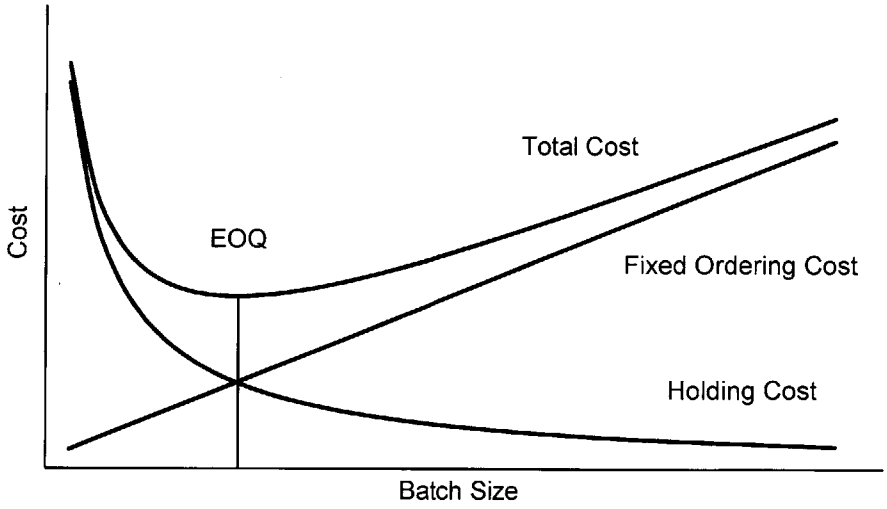


Figure 4 EOQ Cost Plot

2. *Use of the exact best solution with a mathematical model of the situation.* For example the Wagner-Whitin algorithm minimizes the total costs with dynamic lot sizes.[7] However, the incremental benefit of solving the most optimal batch size is small and implementation of the Wagner-Whitin algorithm can be difficult due to the complexity. Also because the resulting batch sizes can widely vary with time, implementation can be challenging in industries where the desired batch size is constant.
3. *Use of a heuristic method.* This is a simple method based on a set of rules set by the user to determine a batch sizes without a lengthy computation. For example, the heuristic method could be dictated by shipping frequency or a natural lot size such as a package size. Amgen uses a heuristic methodology that sets batch size by the ABC Classification as shown in Section 4.1.3.

Selecting the most appropriate approach depends on several factors such as the focus on cost, ability to frequently change the batch size and the complexity to implement the method. In Section 5.1.1, we discuss these methods in the context of managing the raw material of a drug substance manufacturing site.

[7] Wagner and Whitin, "Dynamic Version of the Economic Lot Size Model."

2.1.4. Safety Stock

Safety stock or buffer stock is the inventory to cover for the variability in demand and lead time. Otherwise it is the average level of stock just before a replenishment arrives. When the demand and lead times are random, have a normal distribution, and when the increments are independent,

$$SS = Z\sqrt{Ave.\,lead\ time \times (Stddev.\,of\ demand)^2 + (Avg.\,Demand)^2 \times (Stddev.\,of\ lead\ time)^2}$$

$$Z = NORMSINV(Service\ level)$$

Where SS is the safety stock, Z is the inverse of the standard normal cumulative distribution of the service level. The service level is the desired probability that a level of safety stock will not lead to a stock out. Because, the safety stock equation above assumes that the lead times and demand have normal distributions, when these distributions are not normal, the accuracy of the equation break down and result in a safety stock that may not be able to produce the desired service level. In Section 5.1.2, we discuss our safety stock recommendations for Amgen.

2.1.5. Average Inventory

We use the average inventory calculation described below to estimate the warehouse requirements for Amgen. With an established batch size, on average, there will be half of the batch size in inventory. The inventory on hand, at any point, that results from these batches is called cycle stock. Next, on average, a full inventory of safety stock is held on hand. Thus, the average inventory of a raw material can be represented as,

$$Average\ Inventory = \frac{Batch\ Size}{2} + Safety\ Stock$$

Figure 5 illustrates the concept of average inventory and cycle stock.

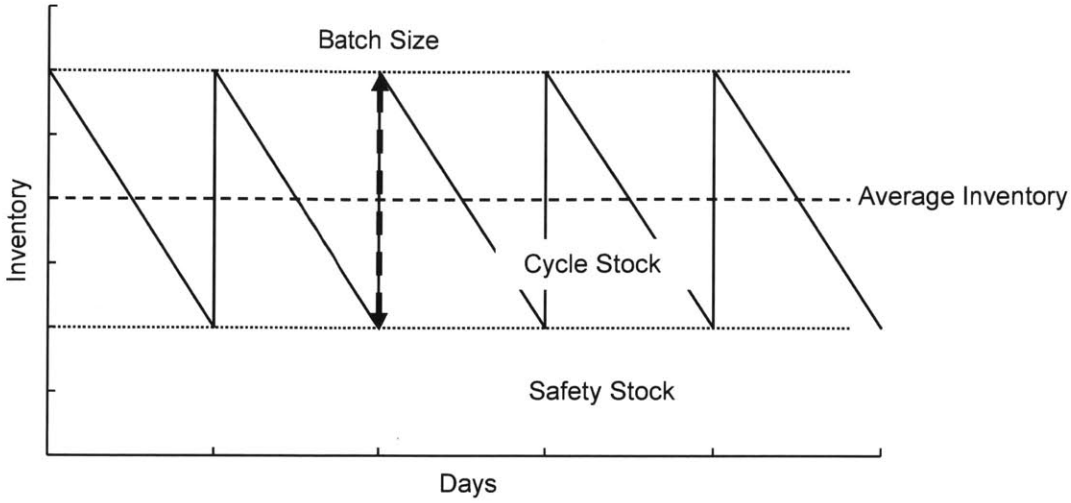


Figure 5 Average Inventory

2.1.6. Commonality

Standardizing parts among different product lines, a practice known as commonality generates economies of scale and other savings such as shorter lead times, lower variable cost, and higher product reliability.[8] For example, recently Proctor & Gamble reduced product cost "over a three-year period as a result of a program of simplification and standardization for a nearly $3 billion in savings".[9]

Raw material commonality reduces the number of raw material SKUs which allows a reduction of total safety stock by the principle of demand pulling and allows a consolidation of cycle stocks of multiple SKUs into one. This results in a lower total inventory. Thus, as Amgen continues to invest in new manufacturing facilities that utilize disposable manufacturing equipment, the raw material SKU commonality between different products will become more important. Currently, Amgen's disposable equipment can make up more than half of the inventory space. In Section 5.1.3, we show the potential for Amgen to gain large savings from commonality.

2.1.7. Vendor Managed Inventory

Vendor Managed Inventory (VMI) is an inventory management practice where a supplier manages the inventory either at the customer's location or supplier's location. With VMI, the customer no longer determines the inventory policy. The customer and the supplier mutually agree on a customer service level

---

[8] Boas and Crawley, "The Elusive Benefits of Common Parts."
[9] Wilson and Perumal, *Waging War on Complexity Costs Reshape Your Cost Structure, Free up Cash Flows, and Boost Productivity by Attacking Process, Product and Organizational Complexity.*

and the inventory policy is set by the supplier. For the supplier to make the replenishment decisions, the customer shares inventory level and demand information. This allows the supplier to be aware of potential demand shifts which mitigates supply chain bullwhip effect. The bullwhip effect refers to the growing swings in supplier inventory in response to the change in customer demand.[10] The benefit of reducing the bullwhip is that it can reduce supplier inventory.[11] VMI can also reduce customer inventory when the inventory is managed at the supplier's location. In this arrangement, the supplier can hold the safety stock for the customer, reducing customer inventory and warehouse usage. In other words, VMI can benefit both the supplier and customer.

To implement VMI, a close relationship between the supplier and customer needs to be formed with demand data shared. During this project, Amgen was in conversation with suppliers to set VMI relationships. We quantify the benefits of using VMI in Section 5.1.4.

2.2. 3rd Party Logistics

3rd Party Logistics (3PL) is a firm that provides supply chain and logistic services. Since the 1980s, the 3PL industry has grown tremendously and large companies across multiple industries such as 3M, Dow Chemical, Time Warner, and Sears started utilizing a 3PL.[12] Third party logistics typically specialize in a service such as transportation or warehousing. For our study, we concentrate on 3PLs for warehousing. The benefits of outsourcing warehousing to a 3PL are:

- *Economies of scale.* A 3PL is be able to aggregate the services from many different customers. The aggregation allows the 3PL to take advantage of economies of scale both from purchasing and in operations.[13]
- *Reduce capital investment.* Using a 3PL can reduce the capital investment such as a construction of a warehouse. The 3PL is able to share the cost of constructing a warehouse between multiple customers.
- *Focus on core competency.* By carefully choosing what to outsource, the customer is able to focus on its core competency that differentiates the company. On the other hand, the 3PL can focus on its core competency which may help the customer through shared technical knowledge or new logistics technologies.

---

[10] Geary, Disney, and Towill, "On Bullwhip in Supply Chains—historical Review, Present Practice and Expected Future Impact."
[11] Cachon and Terwiesch, *Matching Supply with Demand.*
[12] Simchi-Levi, Kaminsky, and Simchi-Levi, *Designing and Managing the Supply Chain.*
[13] Ibid.

Amgen understands all the above potential benefits of a 3PL. In Section 5.2, we discuss our recommendations on how to implement a 3PL in Singapore.

3. Background

The intent of this chapter is to introduce relevant topics to this research. We first introduce Amgen Inc. and the new Singapore manufacturing site and then give an overview of biotechnology manufacturing. Lastly, we discuss the unique qualities of biotechnology raw materials.

3.1. Amgen Inc.

Founded in 1980, Amgen Inc. is considered as one of the early pioneers of biotechnology. Amgen is now the world's largest independent biotechnology company.[14]

Amgen's operations mission is to ensure that their product is available for "every patient, every time." As drug shortages become a growing global concern, Amgen has successfully implemented key practices to help mitigate risk in supply of products.[15] Currently, Amgen is considered one of only few pharmaceutical companies that have not shorted the market of its products.

3.2. Amgen Singapore

Following the mission to serve "every patient, every time," Amgen is building a new manufacturing facility in the Tuas Biomedical Park area of Singapore that will have a more flexible manufacturing capability compared to Amgen's traditional manufacturing facilities. The new facility will be Amgen's first commercial Manufacturing of the Future (MoF) site, using multiple newly developed production technologies.[16] Amgen's MoF initiative provides manufacturing flexibility and increased productivity by leveraging the utilization of disposable equipment, continuous purification processing and real-time quality control.[17] Disposable equipment are as the name implies single-use raw materials. Compared to in conventional manufacturing where reusable stainless steel equipment is used which require high capital investment and long changeover times, disposable equipment reduces cost, while increasing flexibility and configurability.

The new manufacturing site is expected to be completed in 2015 and will have the capability to manufacture both clinical and commercial drug substance.

---

[14] "Amgen - About Amgen - Overview."
[15] Woodcock and Wosinska, "Economic and Technological Drivers of Generic Sterile Injectable Drug Shortages."
[16] "News - 2013 - Amgen Breaks Ground on New Manufacturing Facility in Singapore."
[17] "Introduction to Amgen and Its Manufacturing of the Future Facility in Singapore."

3.3. Biotechnology Manufacturing Overview

Biotechnology manufacturing is different from traditional pharmaceutical manufacturing. Biotechnology products are derived from living cells rather than chemical synthesis and is considered a biotech therapy or biologic.[18] These biologics are considered "large molecules," with molecular weights hundreds of times larger and significantly more complex than the chemical compounds from the traditional pharmaceutical products such as Aspirin or Acetaminophen.

Manufacturing biologics is far more complex than that of drugs based on chemical compounds. This manufacturing process is highly sensitive to the environment. Even subtle changes can affect the cells and alter the product they produce. For that reason, strict process controls are needed to ensure the quality and consistency of the final product. All manufacturing aspects including the specific raw material batch used in production is documented for full traceability such that if there is a contamination or quality issue, the root cause can be discovered and corrected.

Conventional biologic production happens in batches in large fixed stainless steel bioreactors that require large capital investments, have low configurability and have high changeover cost. Amgen's new Singapore site will continue to use a batch production methodology but improve on the cost and flexibility by using disposable equipment.

3.4. Drug Substance and Drug Product

At a high level, there are two production stages in manufacturing a biologic: drug substance manufacturing and drug product manufacturing. Drug substance is the pure substance that acts as the drug while the drug product is the finished dosage form of the product containing the drug substance. The Singapore manufacturing facility is a drug substance manufacturing facility. Thus this research concentrates on drug substance raw materials.

3.4.1. Drug Substance Production Campaign

A production campaign refers to a group of batches of a single product that is produced consecutively. For example, if Amgen has a demand of X batches of a certain product over a year, Amgen groups the X batches and produces it consecutively. By producing the same product consecutively, there are efficiency increases and decreased quality risk. Campaigns can be thought of as a higher level batch

[18] Walsh, "Biopharmaceuticals, an Overview."

size to decrease changeover cost and setup risk. Over a year, there may be several campaigns of the same product.

3.5. cGMP Raw Material

Biotechnology raw materials can largely be categorized by cGMP materials and non-cGMP materials. Current Good Manufacturing Practice (cGMP), are guidelines and inspection requirements set by the Federal Drug Administration (FDA) as shown in Table 2.

a) Raw materials and primary packaging materials are stored and handled in a manner which prevents their mix-up, contamination with microorganisms or other chemicals, or decomposition from exposure to excessive heat, cold, sunlight or moisture.
b) Containers of materials are closed, and bagged or boxed materials are stored off the floor.
c) Containers of materials are labeled with respect to identity, lot identification and control status.
d) Materials are sampled and tested or examined in conformance with procedures assuring the absence of contamination with filth, microorganisms or other extraneous substances to the extent necessary to prevent adulteration of finished products.
e) Materials not meeting acceptance specifications are properly identified and controlled to prevent their use in cosmetics.

Table 2 cGMP Raw Material Checklist[19]

Due to the high quality requirements of cGMP materials, cGMP and non-cGMP materials are handled in separate areas of a manufacturing warehouse. As listed in Table 2, all cGMP material go through a sampling and testing process to confirm the raw material and quality. This step is called dispositioning. The cGMP area is further broken down into different storage conditions such as room temperature, refrigerated and frozen with a separate flammable raw material area.

3.5.1. Disposition

As part of the cGMP requirements, all incoming raw materials to a manufacturing site go through a disposition process where the raw material is tested for identification, quality, and contaminants. All raw materials are immediately quarantined when received in the warehouse for appropriate dispositions. Until the raw material has been properly tested, the raw material is not available for use. The dispositioning process can take up to a month to complete based on the complexity of the testing required. Thus, disposition time is considered as part of the lead time and can also make up a significant portion of the overall raw material lead time.

[19] Nutrition, "Good Manufacturing Practice (GMP) Guidelines/Inspection Checklist."

Due to the specialized processes and technologies used in dispositioning, many 3PLs that specialize in warehousing do not have full raw material disposition capabilities.

3.5.2. Supplier Manufacturing Lot Size

The supplier manufacturing lot size is otherwise known as the supplier's production lot size. In many cases, the suppliers manufacturing lot size is the minimum batch size Amgen can order from the supplier. When the optimum raw material batch size is smaller than the supplier lot size, the material purchaser will round up the order quantity to the supplier lot size for a purchase order.

3.5.3. Resin

Amgen classifies raw material by type such as a chemical or filter. For the purpose of this research, there is one particular material type that is notable, a resin type. In drug substance manufacturing, a step called chromatography uses resin. Chromatography is a step where the active ingredients of the drug substance are filtered from non-active ingredients. In this step the resin is packed into a column and acts as the filter.

Resin is a special raw material in many ways. Though all raw materials are considered essential for drug substance manufacturing, resins are often single sourced (have one supplier) and have a long lead time. A packed column can be reused but the type of resin is unique to the product and cannot be shared between different products. Due to the special characteristics of resin, a manufacturing site will ensure that it always has two columns of resin for each product the site plans to manufacture. Further, each column worth of resin must be ordered from a different supplier lot to reduce quality risk. Resins are also the highest cost raw material. Just a few resin SKUs that make up less than 1% of the bill of material (BOM) can make up 20% of the total inventory value.

4. Current State

The intent of this chapter is to present Amgen's raw material inventory management practices. This includes the generalized processes and analysis techniques Amgen uses to set batch size and safety stock. In addition, we highlight the warehouse plans for the new manufacturing facility in Singapore.

4.1. Amgen Raw Material Inventory Management

In an industry where product profit margins have been traditionally high (shown in Figure 6) and where product stock outs can severely affect a patient, the stock out cost of a raw material is high.

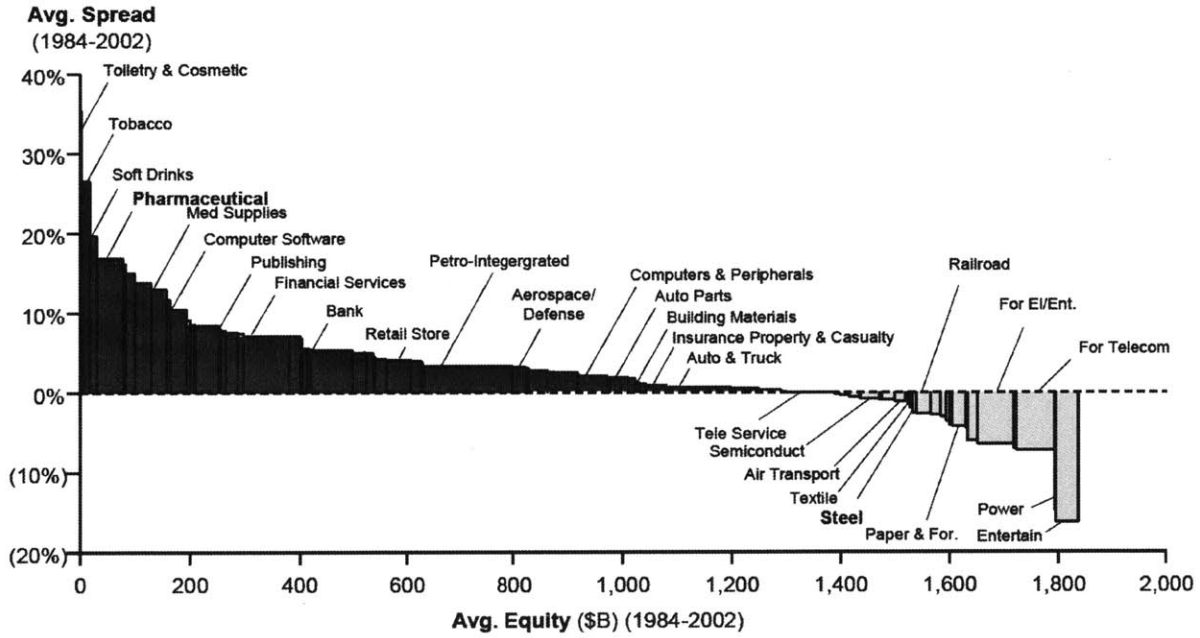


Figure 6 Economic Profits of U.S. Industry Groups, 1984-2002[20]

The financial loss from lost sales or from the resulting negative public relations could be significant. Though it is difficult to quantify the actual value of the stock out cost, we can infer that it is relatively higher than the inventory holding cost due to the high markup. Therefore, Amgen's inventory management strategy has been to keep an appropriate amount of raw material safety stock to minimize the risk of a raw material stock out. With its strong inventory management principles, Amgen has not experienced any major raw material stock out in recent years.

[20] "Economic Profits of U.S. Industry Groups, 1984-2002."

In this section, we explore Amgen's inventory management methods in the attempt to find opportunities to reduce inventory levels while keeping the service level high.

4.1.1. ABC Classification

We first start with Amgen's ABC Classification to understand the distribution of raw materials by value. Amgen's ABC Classification plot shown in Figure 7 is not too dissimilar to the general ABC Classification plot from our literature review in Figure 3.

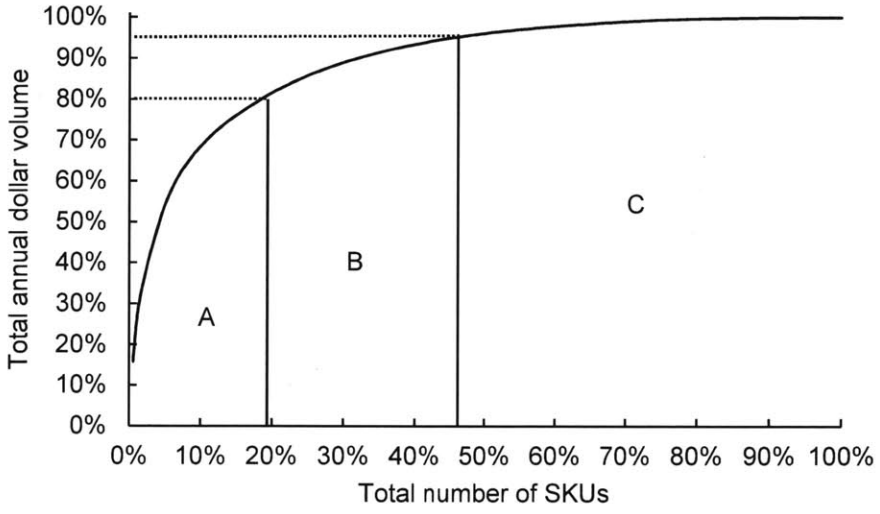


Figure 7 Amgen Raw Material Distribution by Value of SKUs

Relative to Figure 3, Amgen has a fewer number of SKUs in the high value category, A, but has more SKUs in the low value category C. This is due to a few high values items such as resins which are few in SKU number but are very high in value.

4.1.2. Inventory Policy

Amgen uses an (s, Q) inventory policy for simplicity but adds a few additional controls for added risk mitigation. Figure 8 illustrates Amgen's overall inventory policy.

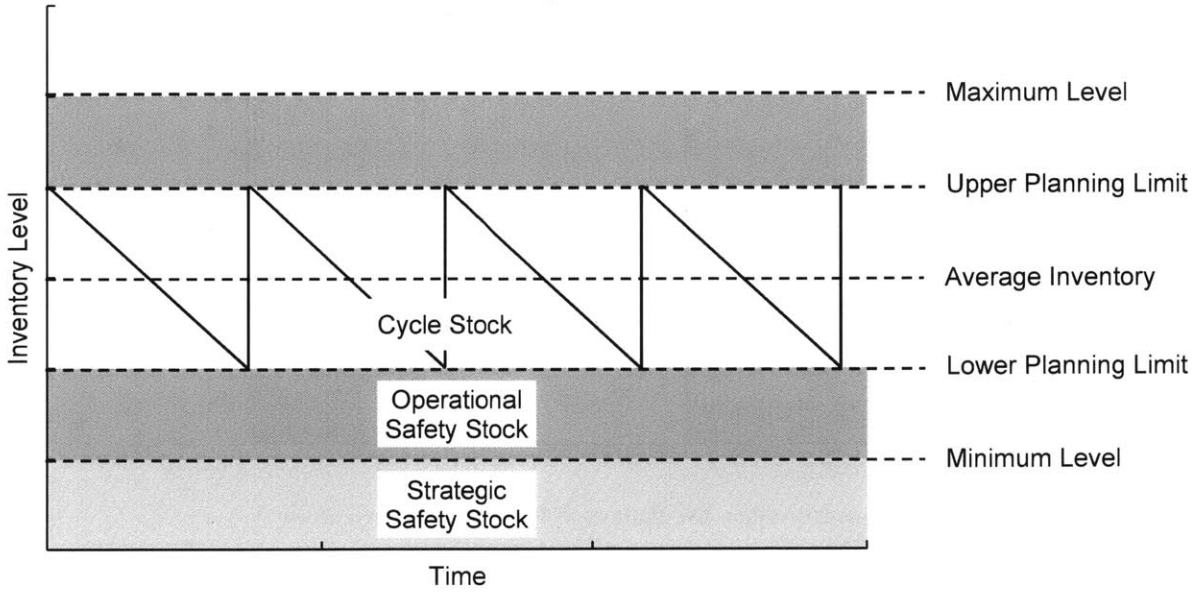


Figure 8 Amgen Inventory Policy

- *Maximum Level* is the scrap threshold and ensures that the total inventory does not force the raw material to expire before use
- *Upper Planning Limit* is the Lower Planning Limit + Batch Size
- *Average Inventory* is Lower Planning Limit + 50% of Batch Size
- *Lower Planning Limit* is the target total safety stock including the operational and strategic safety stock
- *Minimum Level* is the minimum strategic safety stock level that should only be used in one-time events such as a contamination or a natural disaster

The concept of operational safety stock and strategic safety stock is explained in Section 4.1.4. The breakdown of inventory value and warehouse usage by cycle stock, operational safety stock and strategic safety stock is shown in Figure 9.

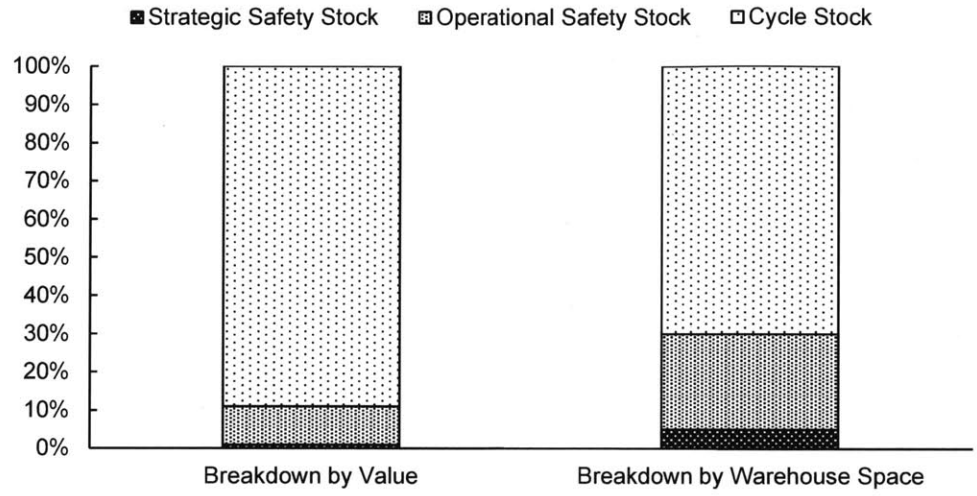


Figure 9 Amgen Breakdown of Raw Material Inventory

We can see that both in terms of value and warehouse usage, cycle stock makes up the largest portion of the inventory. The second largest portion is operational safety stock. Thus, in the future state analysis in Section 5.1, we concentrate on the reduction of batch size and operational safety stock.

4.1.3. Batch Size

Amgen's drug substance demand is mainly deterministic and varies with time. The occasional variation in demand comes from one-time events such as a contamination in a manufacturing batch. From the three different methods to set batch size explained in Section 2.1.3, Amgen uses a heuristic approach using the ABC Classification.

Amgen sets batch size in units of month's forward coverage (MFC). The MFC is determined by the ABC Classification as shown in Table 3:

ABC Classification	Batch Size
A	2 MFC
B	4 MFC
C	6 MFC

Table 3 Amgen Batch Size

Amgen's method to set batch size is easy to calculate and inherently handles raw material expiry by limiting the batch size at 6 MFC. However because more than half of the materials are categorized as C, the cycle stock is inflated by the C category items.

The MFC determined using Amgen's method (MFC_{AMGEN}) behaves similarly to the MFC determined using the EOQ (MFC_{EOQ}) with respect to the annual dollar volume of a SKU. Using the equation from Section 2.1.3, the MFC_{EOQ} can be calculated as follows,

$$EOQ = \sqrt{\frac{2AD}{vr}}$$

$$MFC_{EOQ} = \frac{EOQ}{D/12}$$

$$MFC_{EOQ} = 12\sqrt{\frac{2A}{Dvr}}$$

In this equation, the product of the demand, D and purchase cost, v is the annual dollar volume of a SKU. Then MFC_{EOQ} is inversely proportional to the square root of the annual dollar volume. Likewise, MFC_{AMGEN} follows a similar directional behavior with respect to the annual dollar volume of a SKU.

Relative Annual Dollar Volume	Relative Batch Size (MFC_{AMGEN})
High (A Classification)	Small (2 MFC)
Medium (B Classification)	Medium (4 MFC)
Low (C Classification)	Large (6 MFC)

Table 4 Relative Batch Size by Relative Annual Dollar Volume

Table 4 shows that if the annual dollar volume is high (i.e. SKU with an A classification), MFC_{AMGEN} goes down, and vice versa. Thus, Amgen's method has the same directionality of the EOQ with respect to the annual dollar volume. However, Amgen's method does not account for the fixed ordering cost or holding cost and does not optimize total inventory costs.

Once the batch size is determined using Amgen's method, individual site planners convert the batch size from an MFC into actual raw material measurement units. The planner then ensure that that the order quantity is rounded to the nearest supplier lot size. The batch size for resins receive a modified treatment to ensure that there are always at least two columns worth of resins as explained in Section 3.5.3.

Overall, Amgen's batch size methodology is simple to implement and outputs a constant batch size for easy supplier negotiation and shipment. In Section 5.1.1, we discuss an alternative method in the attempt to reduce inventory.

4.1.4. Safety Stock

Amgen's safety stock is divided into operational safety stock and strategic safety stock. Operational safety stock mitigates against the variability in demand and uses the concept of safety stock defined in Section 2.1.3. Strategic safety stock mitigates against events beyond the normal supply and demand variability (i.e. natural disasters, one-time events, contamination, etc.).

4.1.4.1. Operational Safety Stock

Amgen uses a modified equation of safety stock from the equation shown in Section 2.1.3 as shown,

$$SS = Z\sqrt{Ave.\,lead\ time \times (Stddev.\,of\ demand)^2 + \cancel{(Avg.\,Demand)^2 \times (Stddev.\,of\ lead\ time)^2}}$$

$$SS = Z\sqrt{Ave.\,lead\ time \times (Stddev.\,of\ demand)^2}$$

The term with the standard deviation of lead time is cancelled out with the assumption that the variation of lead time is negligible. We test this assumption and the assumptions required for the use of the safety stock equation.

Lead Time

Amgen's raw material lead time is composed of the suppliers lead time and the disposition lead time. To obtain the supplier lead times, we must go through a manual calculation; we subtract the raw material order date from the receipt date. However, because the raw material purchasing process encourages planners to submit a purchase order earlier than the order required date (based on the quoted lead time), the resulting supplier lead time is often inflated. Though a separate sourcing group tracks on time delivery metrics at a supplier level, it is difficult to break down the lead times by SKU.

The disposition lead time is tracked in different systems at each manufacturing site and is not consolidated into one database. A plot of the disposition lead times in Figure 10 show that the variation in disposition time is relevant.

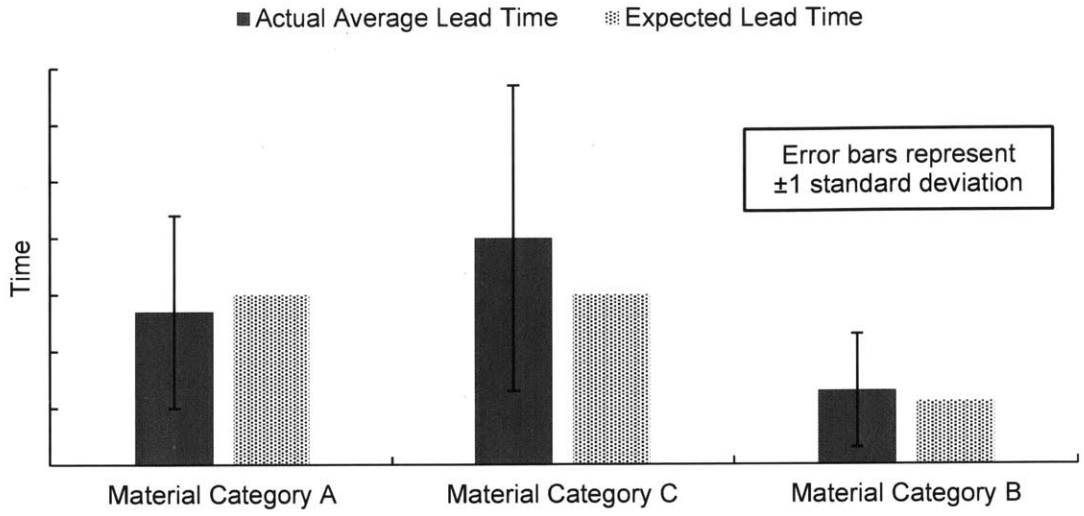


Figure 10 Mean and Standard Deviation of Disposition Lead Time

Though further work is required to understand the variation in supplier lead times, we can see that the variation in disposition time alone is relevant in determining safety stock.

Demand

Though the use the safety stock equation requires the assumption that the demand is random and normal, Amgen's drug substance demand is mostly deterministic and does not have a normal distribution. If we look at an example of a raw material consumption forecast in Figure 11, due to lot campaigning, we see a period of steady demand and a period of no demand.

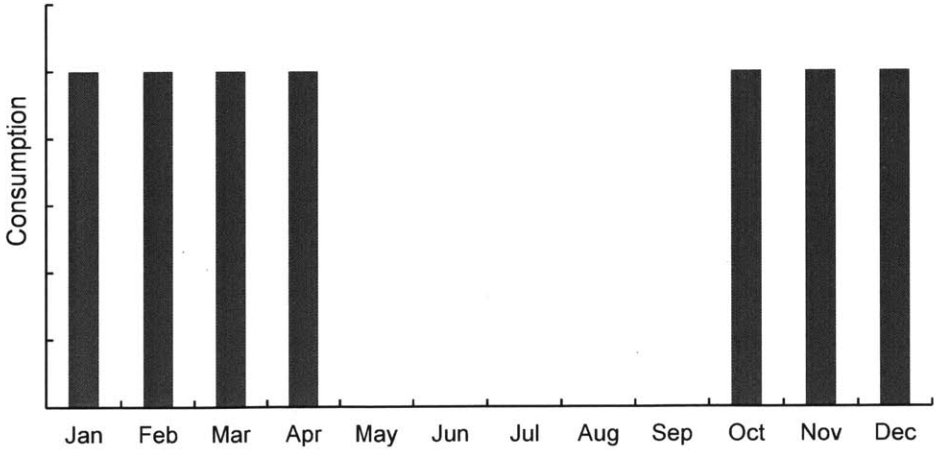


Figure 11 Raw Material Consumption Forecast Example

Amgen calculates the standard deviation of consumption using the consumption forecasts such as in Figure 11. However, the resulting standard deviation in a typical probabilistic analysis is inflated because the

demand variation is deterministic and not probabilistic. In Section 5.1.2, we propose an alternative method to set operational safety stock.

4.1.4.2. Strategic Safety Stock

Amgen holds strategic safety stock for about 5% of raw material SKUs determined by the Category Supply Chain Managers. The managers choose the strategic safety stock level based on experience including risk factors such as sourcing diversification, ease of sourcing, supplier financial health and the history of supply disruptions. Strategic safety stock mitigate against the one-time events while increasing the total inventory by only a small percent as seen in Figure 9.

4.1.5. Raw Material for Clinical vs Commercial Manufacturing

Clinical manufacturing refers to the production of products for clinical drug trials. Commercial manufacturing refers to the production for commercial sales of the product. Though the manufacturing steps for both manufacturing are similar, the scale and timeline of the manufacturing are different. For commercial manufacturing, tens of batches are manufactured over a period of months, while for clinical manufacturing, only several batches are manufactured over a period of weeks.

There is higher risk for clinical manufacturing because there is no upstream inventory in the event of a manufacturing error or a raw material quality issue. Thus to mitigate the risk of a stock out in case of a failed batch, Amgen holds a relatively large raw material safety stock for clinical manufacturing compared to if the safety stock was scaled down based on the number the batches from commercial manufacturing. Unlike the trend in Figure 9, the clinical safety stock is larger than the clinical cycle stock.

Raw Materials for Commercial Manufacturing

Amgen holds strategic safety stock, operational safety stock and cycle stock for commercial production. Due to the long duration and the quantity of raw materials used, a continuous review inventory policy is used. Because commercial products are campaigned, the cycle stock is cycled on and off as a campaign starts and ends. At the end of a campaign, the leftover raw materials are stored in the warehouse until the next time the same product is campaigned. The raw material inventory timeline for commercial manufacturing is illustrated in Figure 12.

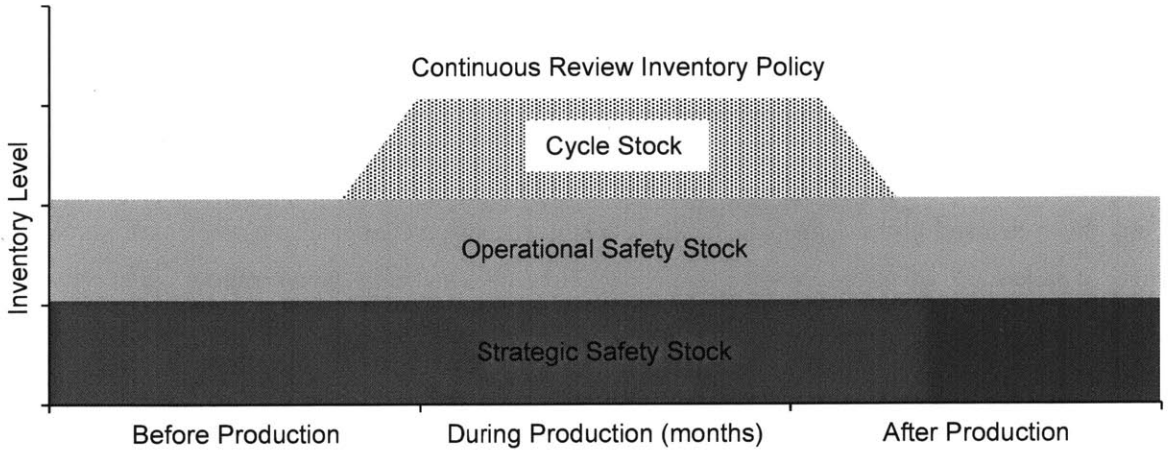


Figure 12 Raw Material Inventory Commercial Manufacturing

Raw Materials for Clinical Manufacturing

For clinical production, due to the short duration of production and the smaller quantity of raw materials needed, all of the raw material is purchased up front without an inventory policy. The clinical safety stock is also calculated differently than for commercial manufacturing. The clinical safety stock is set to ensure that there is double the raw material while also ensuring that half of the ordered raw material comes from a different supplier lot. Further, regardless of the manufacturing type, the order quantity for resin is set such that there are two columns worth of resin in inventory. The raw material inventory for clinical manufacturing is illustrated in Figure 13.

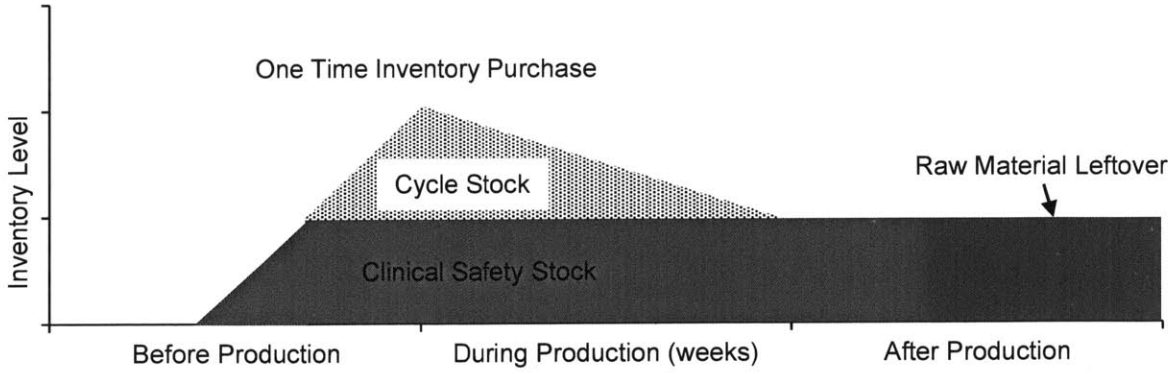


Figure 13 Raw Material Inventory Clinical Manufacturing

At the end of a clinical campaign, there is roughly the equal amount of raw material leftover compared to that at the end of a commercial campaign. However, typically a clinical product will not be produced in consecutive years. There is also a chance that the clinical product will not be produced again at all. As a result, over time, a manufacturing facility that engages in frequent clinical production will overload its

warehouse by leftover raw materials that have no plans for use but are far from expiry. To combat this issue, we discuss the use of commonality in Section 5.1.3.

4.1.6. Baseline Warehouse Model

We create a baseline warehouse model to estimate the space required to hold necessary raw material for any given demand in the Singapore facility. This warehouse model calculates the space required, in number of pallets, taking into account the batch size, safety stock and pallet conversion. A pallet conversion is the raw material quantity that fits on a pallet. Through the current state analysis, we find that, there is a significant space constraint in future years of the warehouse as shown in Figure 1. At peak production, the safety stock alone (without any cycle stock) could capacitate Amgen's internal warehouse.

The warehouse model uses the following steps to calculate the space required in number of pallets.

1. Batch size and safety stock is calculated based on Amgen's methodology explained in section 4.1.3 and 4.1.4 for each raw material using the manufacturing forecast.
2. The average inventory for each raw material is calculated using the following equation,

$$Average\ Inventory = Safety\ Stock + \frac{1}{2} Batch\ Size$$

3. The average inventory is converted into average pallets for each raw material using the following equation,

$$Average\ Pallets = \frac{Average\ Inventory}{Pallet\ Conversion}$$

4. The average pallets are then summed up to for the total space required of each storage condition.

A simplified version of the warehouse model is shown in Table 5.

Material	Storage Conditions	Unit	CS	OSS	SSS	Avg Inv	Pallet Conversion	Pallets
1	2 - 8C	g	72,000	117,000	-	189,000	180,000	2
2	Room Temperature	g	108,000	200,000	-	308,000	200,000	2
3	2 - 8C	g	12,000	130,000	-	142,000	180,000	1
4	Room Temperature	g	120,000	91,000	-	211,000	90,500	3
5	Room Temperature	g	24,000	26,000	-	50,000	200,000	1
6	Room Temperature	g	168,000	78,000	-	246,000	363,200	1
7	Room Temperature	g	120,000	78,000	-	198,000	363,200	1
8	Room Temperature	g	48,000	104,000	-	152,000	570,000	1
9	Room Temperature	ml	48,000	39,000	-	87,000	456,000	1
10	≤ -10C	g	168,000	26,000	-	194,000	456,000	1
11	2 - 8C	g	36,000	200,000	-	236,000	43,200	6
12	Room Temperature	ml	240,000	78,000	-	318,000	217,200	2
13	Room Temperature	ml	-	65,000	-	65,000	217,200	1
14	Room Temperature	g	48,000	78,000	-	126,000	363,200	1
15	Room Temperature	ml	72,000	65,000	-	137,000	302,000	1
16	Room Temperature	g	192,000	78,000	13,000	283,000	162,000	2
17	2 - 8C	g	48,000	104,000	-	152,000	180,000	1
18	2 - 8C	g	72,000	117,000	-	189,000	180,000	2
19	Room Temperature	g	96,000	65,000	-	161,000	200,000	1
20	2 - 8C	g	120,000	104,000	-	224,000	180,000	2

Table 5 Example Baseline Warehouse Model

4.1.7. Expected Inventory vs Actual Inventory

We compare the expected raw material inventory (using the baseline warehouse model in the previous section) versus Amgen's actual raw material inventory of an existing manufacturing facility. The analysis shows that the actual inventory is 10% greater than the expected inventory. We identified that there are three main causes for the discrepancy; 1) suppliers do not package the materials to fully utilize pallets, 2) pallet conversion information in SAP is incorrect, and 3) materials are not picked optimally by the warehouse staff. Further work is required to resolve these inconsistencies as a 10% increase in inventory at

Singapore could be costly with the potential of a capacity overload. In Section 5.2.3, we introduce key performance indicators that help in mitigating this discrepancy.

5. Future State

In this chapter we evaluate methods to reduce inventory and to effectively use a 3PL. We begin by reviewing alternative methods to set batch size and safety stock. Further we discuss the potential benefits of commonality and vendor managed inventory. Lastly, we present different ways to utilize a 3PL as a secondary warehouse. Because the Singapore site was still in construction during the project, the methods discussed in this section was not implemented but the potential benefits are quantified.

5.1. Inventory Management

As discussed in the literature review, inventory management principles have a great potential to reduce inventory and cost. Four techniques of managing inventory is discussed in this section; batch size, safety stock, commonality and vendor managed inventory.

5.1.1. Batch Size: Implied Cost of Space

We first attempt to use the EOQ outlined in Section 2.1.3 to find the cost optimal batch size. Amgen's inventory holding cost is estimated at 8-10%. However, determining an accurate fixed ordering cost is difficult due to the different administrative aspects that are part of the raw material ordering process. Thus, we instead develop an extension of the EOQ that can dynamically change the batch size to the warehouse size without the input of the fixed ordering cost. We call this EOQ extension the "implied cost of space method."

The extension of the model uses the EOQ formula and inserting a Lagrangian multiplier, λ, common to all raw materials.[21] The resulting solution is the upper bound of the set of batch sizes that will allow the total inventory to fit within a capacity constraint. We start with inserting λ into the EOQ formula,

$$Q_i = \sqrt{\frac{2\lambda A_i D_i}{v_i r}}$$

The subscript i represents each individual raw material. We assume that the fixed ordering cost for all raw materials A_i is equal and modify the equation to,

$$Q_i = \sqrt{\frac{2\lambda' D_i}{v_i r}}$$

[21] Winston, *Introduction to Mathematical Programming.*

By adding the sum of all the raw material pallets and setting the result equal to the total available warehouse space, W, we can solve for λ'. The Lagrangian multiplier, λ' is a shadow price for the combination of the implied cost of a space (or pallet position) and cost of ordering.[22]

$$W = \sum roundup\left(\frac{\frac{Q_i}{2} + SS_i}{PC_i}\right)$$

$$W = Total\ Pallets\ Occupied$$

$$Q_i = Batch\ Size$$

$$SS_i = Safety\ Stock$$

$$PC_i = Pallet\ Conversion$$

Substituting the equation for Q_i into the equation for W and solving for λ' yields the following result,

$$\lambda' = \left(\sqrt{\frac{W - \sum roundup\left(\frac{SS_i}{PC_i}\right)}{\sum\left[roundup\left(\frac{1}{PC_i}\sqrt{\frac{\lambda' D_i}{2r}}\right)\right]}}\right)^2$$

The batch sizes are then calculated using the modified EOQ formula. Table 6 shows an example calculation.

[22] Rosenfield, Thesis Supervisor.

Holding Cost (r)	8%			
Available Pallets	30			
Warehouse Utilization Target	80%		Lagrange Multiplier (λ')	827.60
Target Pallets	24		Total Pallets Occupied (W)	24

Material	Unit	Unit Cost (v)	Demand (D)	EOQ	Safety Stock (SS)	Pallet Conversion (PC)	Pallets
1	g	$0.0912	1,959,400	666,721	206,639	270,000	2
2	g	$0.5926	577,200	141,959	61,880	180,000	1
3	mg	$19.1200	270,700	17,115	20,063	100,000	1
4	g	$0.4146	54,820	52,304	5,412	180,000	1
5	g	$0.1192	331,660	239,932	35,557	180,000	1
6	g	$0.2842	760,960	235,369	75,118	180,000	2
7	g	$0.2962	2,211,600	393,044	218,316	180,000	3
8	g	$0.5862	5,560,360	443,005	548,887	180,000	5
9	g	$0.2708	3,635,320	527,020	358,858	180,000	4
10	g	$0.2782	6,651,350	703,326	212,150	180,000	4

Table 6 Example Batch Size Calculation

The inventory levels for each raw material are controlled by the Lagrangian multiplier or the implied of cost space to minimizing total cost. For example, in the standard EOQ formulation, if we lower the order cost, to minimize total cost, the order frequency must to increase (while the order quantity must decrease) resulting in decreased inventory levels. Using this principle, the model optimizes the implied cost of space to control inventory levels to fit within the warehouse capacity.

This method allows Amgen to set the batch size such that the total inventory fit within the warehouse without explicitly knowing the ordering costs. In the long term, using this method may become more difficult as the safety stock and the leftovers alone will capacitate the warehouse. Nonetheless in the short term using this method allows Amgen to reduce raw material batch sizes and to push out the need of using a 3PL.

5.1.2. Operational Safety Stock

Amgen sets the operational safety stock assuming that the demand is random and normally distributed. However, as explained in Section 4.1.4.1, Amgen's drug substance demand is mostly

deterministic and is set 18 months ahead by the planning organization. Since the demand is not random, there is potential to reduce operational safety stock. If Amgen can formally fix the drug substance schedule by 6 months (to cover all the raw material lead times), we can formally state that the demand is deterministic. This would allow Amgen to reduce raw material inventory held at Singapore by 10% and reduce warehouse usage by 18%. We recommend Amgen to start considering formally fixing the drug substance demand schedule by 6 months to reduce operational safety stock levels significantly.

5.1.3. Commonality

The purpose of using raw material standardization or commonality is to reduce raw material inventory by risk pooling and to reduce cost by economies of scale as introduced in Section 2.1.6. As the Singapore facility starts producing multiple products using the MoF process, there is a great risk if commonality is designed out of future products. In our warehouse analysis, we assume that 75% of the disposable raw materials is standardized across different products. If the commonality decreases, the resulting increase in supply chain costs can be significant. For example, if commonality decreases to a lower 25%, the room temperature pallets will increase by 46% (increase of the overall inventory value by 8%) and will result in an annual 3PL cost increase of hundreds of thousands of dollars.

Amgen should ensure raw material commonality in new products starting now. Once at the commercial manufacturing stage, even a small change in the process can be costly. With the start of the new MoF site in Singapore, Amgen is in a good starting position to initiate commonality practices and should incentivize new process development engineers to standardize raw materials early in the process.

5.1.4. Vendor Managed Inventory

To minimize the reliance of a 3PL, Amgen can also utilize Vendor Managed Inventory (VMI) at the supplier's location. Assuming Amgen is able to partner with two of Amgen's main suppliers in Singapore, Amgen can potentially reduce inventory value by 5% and reduce the number of raw material pallets by 15%. In this calculation we assume that the two suppliers will carry their respective safety stock of raw materials at their own location decreasing Amgen's warehouse requirements.

Creating a VMI relationship requires time to build up trust and to roll out the right IT systems to share the demand and supply information. Amgen has already started looking into this process in Singapore and is in a great position to reduce inventory levels in its manufacturing facility. At the time of this analysis, we did not have information on the potential costs from starting VMI. Though Amgen still needs to work out the details on supplier's storage cost and/or increased unit cost, Amgen should continue the conversation with suppliers and weigh the cost and benefit before implementing VMI in Singapore.

5.2. 3rd Party Logistics

Despite the potential to decrease inventory using the inventory management practices introduced above, Amgen will still require a 3PL in Singapore. In this section, we will discuss the future state analysis on how to utilize a 3PL.

Amgen's utilization of a 3PL is a multi-echelon problem, where inventory should be optimized across the entire supply chain accounting for the impact of inventory at both the 3PL and Amgen's warehouse. Though there are approaches to deal with complex multi-echelon problems as described by Silver et al, Amgen's Singapore supply chain is a simple multi-echelon problem.[23] As such there are two methods to utilize a 3PL as a secondary warehouse. The first option is to use the 3PL in parallel with Amgen. In this option raw material SKUs are divided between the 3PL and Amgen's warehouse. Each supplier delivers raw material to either the 3PL or Amgen. When the raw materials are needed, both locations independently move materials directly to the manufacturing floor. The second option is to use the 3PL in series with Amgen. In this option, raw materials go through both the 3PL and Amgen's warehouse. Suppliers ship the materials to the 3PL and subsequently the material is shipped to Amgen's warehouse when it is needed. All raw materials pass through Amgen's warehouse before arriving at the manufacturing floor.

The method chosen should be one that takes into account the limitations of the 3PL, have a lower quality risk with minimal material transfers and yield lower inventory.

5.2.1. Parallel

Utilizing a 3PL in parallel has the potential for lower inventory than a 3PL in series because each raw material SKU is stored in only one location. Despite the benefit, we do not recommend a 3PL in parallel for two reasons. First and most importantly, Amgen requires to have dispositioned raw material inventory on site. Though this could change in the future, the purpose is to recommend a solution that fits within Amgen's standards. Second, the parallel method could double the number of raw material transfers between the 3PL and Amgen, which increases quality risk from contamination and temperature excursions. We expect the 3PL to have limited dispositioning capabilities which will require the raw materials to be transferred back and forth to Amgen for dispositioning. Though utilizing a 3PL in parallel may lower inventory, we do not recommend it because it does not meet Amgen's raw material requirements and increases quality risk.

---

[23] Silver et al., *Inventory Management and Production Planning and Scheduling.*

5.2.2. Series

We recommend, utilizing a 3PL in series. The series method allows raw materials to flow one way. SKUs that take up large space are supplier delivered to the 3PL and transferred to Amgen when needed while SKUs that take up small space are directly delivered to Amgen. Because some of the raw materials are supplier delivered directly to Amgen, we can think of this system as a half-series system. We create a set of rules to minimize the transfer of raw materials between the 3PL and Amgen's warehouse while standardizing the 3PLs dispositioning requirement. Here are the rules,

1. Raw material leftovers from previous years are stored at the 3PL.
2. Raw materials (for commercial production) with high safety stock greater than 1 pallet are shipped to the 3PL. The 3PL will disposition these raw materials. The tested raw materials are delivered to Amgen when needed.
3. All other raw materials (small space items) for commercial production are shipped to Amgen.
4. Raw materials for clinical production are all shipped to the 3PL. The 3PL will disposition these raw materials. The tested raw materials is delivered to Amgen when needed.

Figure 14 illustrated a pictorial representation of Amgen and the 3PL in series.

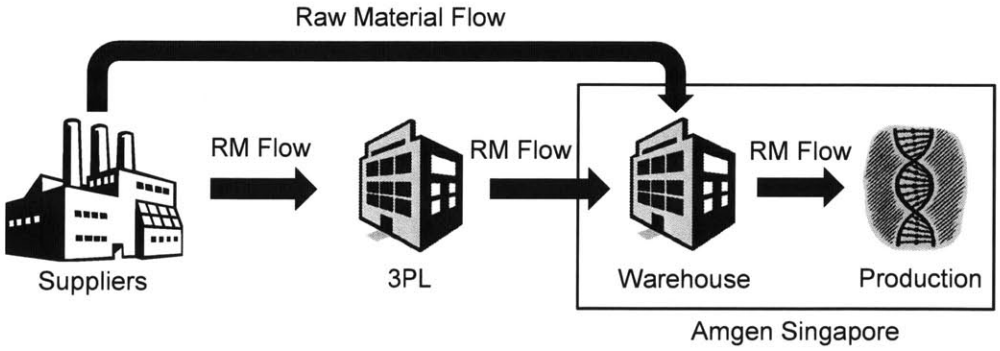


Figure 14 Amgen and 3PL in series

Table 7 shows a simplified example of the heuristic where a commercial drug substance campaign is followed by a clinical drug substance campaign with no overlap. In this example, we look at a storage area that has a capacity limit of 9 pallets.

Available Pallets				9					
Warehouse Utilization Target				80%					
Target Pallets				7					
Past Raw Material Leftover Pallets				5					
Material	**Commercial or Clinical**	**Safety Stock**	**Cycle Stock**	**Average Inventory**	**Pallet Conversion**	**Average Pallets**	**Pallets from Safety Stock**	**Pallets from Cycle Stock**	**Ship to 3PL/ASM**
1	Commercial	264,674	93,000	696,511	150,000	5	1.9	3.1	3PL
2	Clinical	136,748	94,500	420,764	140,000	4	1.3	2.7	3PL
3	Commercial	158,179	55,000	351,509	100,000	4	1.8	2.2	3PL
4	Commercial	533,186	94,400	1,300,453	160,000	10	4.1	5.9	3PL
5	Commercial	38,110	90,000	152,441	120,000	2	0.5	1.5	ASM
6	Clinical	380,398	67,500	869,480	120,000	8	3.5	4.5	3PL
7	Clinical	542,108	108,000	1,355,269	180,000	8	3.2	4.8	3PL
8	Commercial	67,788	144,000	338,939	180,000	2	0.4	1.6	ASM
9	Clinical	121,662	99,000	270,360	180,000	2	0.9	1.1	3PL
10	Clinical	72,653	108,000	181,633	180,000	2	0.8	1.2	3PL

Table 7 Sample Warehouse Model with 3PL

Table 8 shows the calculation of estimated maximum pallets during commercial production and clinical production for both the 3PL and Amgen.

	During Commercial Production		**During Clinical Production**	
Past Raw Material Leftover	3PL: Leftovers	5 Pallets	3PL: Leftovers	5 Pallets
Raw Material for Commercial	3PL: SS_h+CS_h	19 Pallets	3PL: SS_h	8 Pallets
	Amgen: $SS_l+CS_l+CS_h$	7 Pallets	Amgen: SS_l	2 Pallets
Raw Material for Clinical	-	-	3PL: SS_c+CS_c	23 Pallets
			Amgen: CS_c	5 Pallets

Table 8 Calculation Warehouse Model with 3PL

The safety stock, cycle stock and leftovers are split among the 3PL and Amgen's warehouse where,

- SS_h = Total safety stock for commercial production raw materials with high safety stock
- CS_h = Total cycle stock for commercial production raw materials with high safety stock
- SS_l = Total safety stock for commercial production raw materials with low safety stock
- CS_l = Total cycle stock for commercial production raw materials with low safety stock
- SS_c = Total safety stock for clinical production raw materials

- CS_c = Total safety stock for clinical production raw materials

The summary of the results are shown in Table 9.

	During Commercial Production	During Clinical Production	Capacity
3PL Pallets	24	36	N/A
Amgen Pallets	7	7	7

Table 9 Summary Results of Warehouse Model with 3PL

Table 9 shows that the created methodology keeps Amgen's storage area within its capacity while dynamically changing 3PL inventory.

5.2.3. Key Performance Indicators

The results of the warehouse model rely upon accurate input data and assume that the calculated expected inventory accurately represents the warehouse during operation (discussed in Section 4.1.7). We recommend Amgen to track the following key performance indicators (KPI) in Table 10, at the new manufacturing facility to ensure the correct inventory management decision are made.

KPI	Attribute
BOM accuracy	Material quantity is accurate
Manufacturing schedule performance	On time drug substance lot starts
Inventory record accuracy	SAP warehouse inventory is accurate
Master data accuracy	Lead time, pallet conversion & vendor lot size is accurate
Purchase Order (PO) release to supplier	On time PO release to supplier
Supplier delivery	On time delivery
3PL delivery to Amgen	On time delivery
Supplier packaging	Raw material packaged to specification
Raw material picking	Raw material picked to minimize pallets

Table 10 Recommended Key Performance Indicators

6. Conclusion

We conclude with recommendations and opportunities for further research. We present recommendations for Amgen and generalized recommendations that applies to other firms and industries. Recommendations are based on our research during the six month project. The future study opportunities are extrapolations of the project.

6.1. Recommendations

We recommend Amgen the following actions to reduce raw material inventory in Singapore,

Recommendation Description	Opportunity or Risk (Annualized)
Use the "Implied Cost of Space" method to set Batch Size	3PL requirement deferral
CP4 Operational Safety Stock reduction by firming 6 months of production	10% inventory reduction 18% pallet decrease
Vendor Managed Inventory for Safety Stock with two major suppliers at Amgen	5% inventory reduction 15% pallet decrease
Decrease in Single Use System BOM Commonality (75%->25%)	8% inventory increase 46% room temperature pallet increase

Table 11 Opportunities & Risks

A flexible and scalable warehouse model was created to manage inventory between the 3PL in series with Amgen's warehouse. The model calculates the raw material required for a given production plan and determines how to route the raw material and the space required by Amgen and the 3PL. We recommend Amgen to implement the key performance indicators in Table 10 and use the warehouse model for raw material inventory planning.

Firms facing inventory storage challenges should take the following four step process to solve their problems. First, the firm should understand their inventory policy and expected inventory. This should include a deep understanding of the methodology used to determine safety stock and batch size. Second, the firm should ensure that the safety stock level is appropriate for the desired service level and should optimize batch size to ensure cost and space is optimized. Third, the firm should consider other inventory management principles to decrease inventory such as commonality and VMI. Lastly, the firm should ensure that the expected inventory in the model accurately represent reality by testing the model to reality and using appropriate KPIs to track key performance measures.

6.2. Opportunities for Further Research

As the Singapore manufacturing site ramps up in production, the warehouse model will be used to manage the Singapore supply chain. Though the scope of this project was focused primarily on the new Singapore site, the warehouse model was built with the capability to expand to all sites and geographies. Using the warehouse as a foundation, there is potential to save millions of dollars by optimizing all of Amgen's raw material inventory management, including the batch size and safety stock.

We recommend Amgen to explore the use of the EOQ or Wagner-Whiten approach to set batch sizes across all manufacturing sites. If Amgen decides to continue to use the ABC Classification to set batch sizes, we recommend Amgen to develop an approach that takes into account the space requirement for each SKU. Though Amgen's ABC Classification method to set batch approximately minimizes cost, it does not take into consideration the few SKUs that take up a large number of pallets in the warehouse. Lastly, we recommend Amgen to include the variation of lead time in the calculation of operational safety stock.

7. References

"Amgen - About Amgen - Overview." Accessed February 7, 2014. http://www.amgen.com/about/overview.html.

"Amgen To Build State-Of-The-Art Manufacturing Facility In Singapore -- THOUSAND OAKS, Calif., Jan. 16, 2013 /PRNewswire/ --." Accessed February 3, 2014. http://www.prnewswire.com/news-releases/amgen-to-build-state-of-the-art-manufacturing-facility-in-singapore-187179581.html.

Boas, Ryan, and Edward Crawley. "The Elusive Benefits of Common Parts." *Harvard Business Review* 89, no. 10 (October 2011): 34–34.

Cachon, Gérard, and Christian Terwiesch. *Matching Supply with Demand: An Introduction to Operations Management*. New York: McGraw-Hill, 2013.

"Economic Profits of U.S. Industry Groups, 1984-2002." *Compustat, Value Line, Marakon Associates Analysis*, n.d.

Geary, S., S.m. Disney, and D.r. Towill. "On Bullwhip in Supply Chains—historical Review, Present Practice and Expected Future Impact." *International Journal of Production Economics* 101, no. 1 (May 2006): 2–18. doi:10.1016/j.ijpe.2005.05.009.

"Introduction to Amgen and Its Manufacturing of the Future Facility in Singapore." Accessed February 7, 2014. http://www.bti.a-star.edu.sg/news-events/seminars/2011-present/item/1080-introduction-to-amgen-and-its-manufacturing-of-the-future-facility-in-singapore.html.

"News - 2013 - Amgen Breaks Ground on New Manufacturing Facility in Singapore." *Singapore Economic Development Board*. Accessed February 7, 2014. http://www.edb.gov.sg/content/edb/en/news-and-events/news/2013-news/amgen-breaks-ground-on-new-mfg-facility.html.

Nutrition, Center for Food Safety and Applied. "Good Manufacturing Practice (GMP) Guidelines/Inspection Checklist." WebContent. Accessed February 4, 2014. http://www.fda.gov/cosmetics/guidancecomplianceregulatoryinformation/goodmanufacturingpracticegmpguidelinesinspectionchecklist/default.htm.

Rosenfield, Don. Thesis Supervisor, December 2014.

Silver, Edward A., David F. Pyke, Rein Peterson, 0471119474, and 978-0471119470. *Inventory Management and Production Planning and Scheduling*. 3 edition. Wiley, 1998.

Simchi-Levi, David, Philip Kaminsky, and Edith Simchi-Levi. *Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies*. Boston: McGraw-Hill/Irwin, 2008.

Wagner, Harvey M., and Thomson M. Whitin. "Dynamic Version of the Economic Lot Size Model." *Management Science* 5, no. 1 (October 1958): 89–96. doi:10.1287/mnsc.5.1.89.

Walsh, Gary. "Biopharmaceuticals, an Overview." *Biopharmaceuticals, an Industrial Perspective*, 1999, 1–34.

Wilson, Stephen A, and Andrei Perumal. *Waging War on Complexity Costs Reshape Your Cost Structure, Free up Cash Flows, and Boost Productivity by Attacking Process, Product and Organizational Complexity*. New York: McGraw-Hill, 2010.

Winston, Wayne L. *Introduction to Mathematical Programming: Operations Research*. 4th ed. Pacific Grove, CA: Thomson/Brooks/Cole, 2003.

Woodcock, J., and M. Wosinska. "Economic and Technological Drivers of Generic Sterile Injectable Drug Shortages." *Clinical Pharmacology & Therapeutics* 93, no. 2 (February 2013): 170–176. doi:10.1038/clpt.2012.220.