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MilliporeSigma Inventory Control

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by

Luciana Alvestegui ______________________________

Renée Laliberte _________________________________

Naomi Phillips __________________________________

Date: 03/02/2018

Approved:

______________________________ ______________________________

Professor Amy Zeng, Major Advisor **Professor Sara Saberi, Major Advisor**

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Abstract

The demand for MilliporeSigma’s products has grown annually causing an increase in work in progress inventory. This issue compromises safety, increases costs, and threatens customer service levels. WPI students analyzed the root causes of this issue and recommended improvements to the system through several methods such as Gemba walks, time studies, observations, and interviews. The final deliverables included an implementation plan for the team’s recommendations, the design of a pull system using Kanbans, and a quantitative impact assessment.

1.0 Introduction

1.1 Company Overview

MilliporeSigma is a major manufacturer of filters used in biopharmaceutical manufacturing processes (MilliporeSigma, 2017). MilliporeSigma is under a parent company, The Merck Group, known simply as Merck. Merck is a German based life science company founded in 1668 and it is the world's oldest chemical and pharmaceutical company. Merck has a wide impact on the pharmaceutical industry as their products are used by the majority of pharmaceutical companies. It has more than 60 life science manufacturing sites worldwide, produces more than 300,000 life science products, has a presence in 66 countries, and more than one million life science customers globally (EMD Millipore, 2017).

The history of MilliporeSigma goes beyond its acquisition by Merck. This is especially important to understand how the name MilliporeSigma came about. In 1954, the filtration company that pioneered the use of membranes in a variety of applications, later became identified as the Millipore Corporation. As time proceeded the Millipore Corporation expanded their capabilities and range of products to become a billion dollar, global life science manufacturer. In 2010, the Millipore Corporation was acquired by Merck KGaK (Merck) and became a part of Merck's life science division in North America. During this transition Millipore started using the umbrella brand "EMD", making it EMD Millipore. In 2015, Merck acquired Sigma-Aldrich to combine its strengths with those of EMD Millipore to create a life science powerhouse (MilliporeSigma 2017). Due to this event Merck combined the two subsidiaries to become MilliporeSigma which is the company this project is focused on (Figure 1).

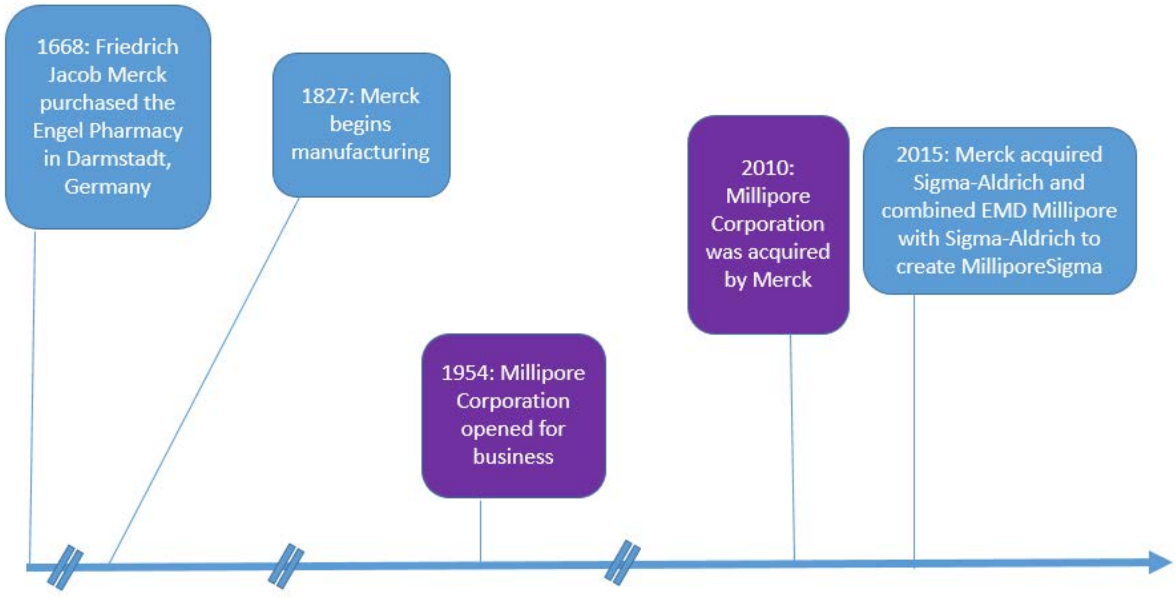

Figure 1: MilliporeSigma Timeline

MilliporeSigma's mission is to help customers improve human health and life worldwide (Mission Statement, 2017). For this purpose, they are ISO 9001 certified. ISO 9001 is a series of tools used to ensure strong customer service while focusing on quality improvement (International, 2017). The MilliporeSigma branch of Merck focuses on life sciences which divides into three different sectors: process, research, and applied solutions. Their headquarters are located in Billerica, Massachusetts and their distribution center is in Taunton, Massachusetts. MilliporeSigma has locations all over the continental US; the site that this project focuses on is in Jaffrey, NH.

1.1.1 Jaffrey, NH Facility

MilliporeSigma's "Center of Excellence" for aseptic filtration devices is in Jaffrey, New Hampshire. The Jaffrey plant began operating in 1972 as a 10,000 square foot facility. As the company experienced growth, eight additions took place from 1973-2015. The site experiences a minimum growth rate of 8% per year and currently has over 950 employees (MilliporeSigma, 2017). This facility produces over 2.5 million devices annually. In order to plan and track high amount of orders the company uses a software called Oracle. The Jaffrey plant builds biopharmaceutical filters that have a variety of applications. This is done by manufacturing subassemblies that can be configured to create different final products.

The plant produces two types of filters: normal and tangential flow. Normal flow products are all single use while the tangential flow products are multi-use. The main difference between these two filters is the direction the solution flows. In a tangential filter, the liquid flows parallel to the surface of the filter and is recirculated until it reaches desired specifications. In a normal flow filter, liquid flows perpendicularly through the membrane pleats once and the purified liquid passes through the membrane (Schwartz, 2017). Normal filters are single use due to the buildup of particles on the membrane that occurs after a product is filtered. Generally, these are used during the final processing of a product.

The facility has a leadership team made up of individuals that specialize in different areas throughout the plant. Figure 2 outlines the structure of leadership.

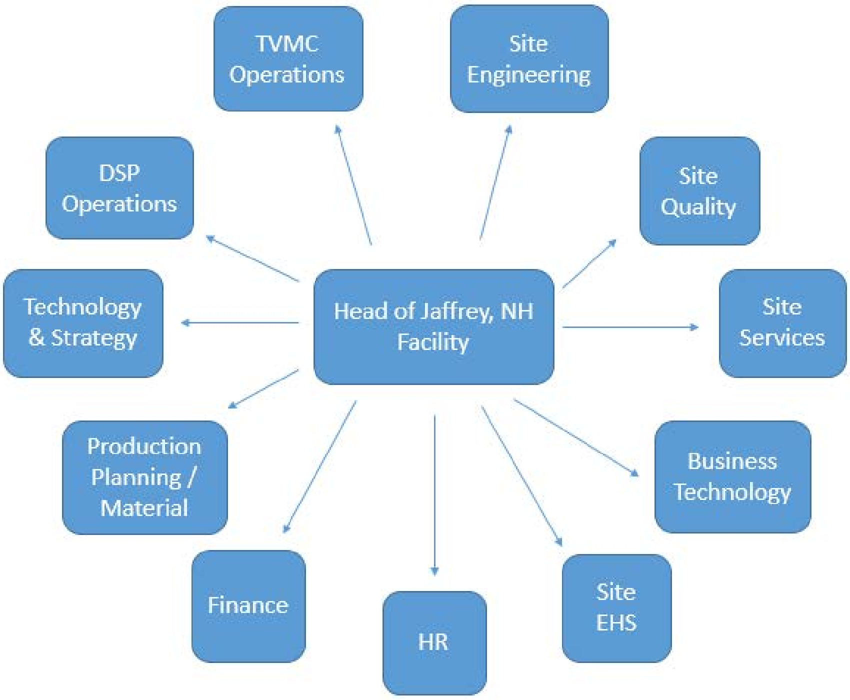

Figure 2: Leadership Structure of the Jaffrey Facility

Over the past decade MilliporeSigma has experienced major growth which lead to an increase in manufacturing problems. Specifically, the site's work in progress inventory increased dramatically. To address this problem MilliporeSigma reached out to Worcester Polytechnic Institute.

1.2 Problem Statement

In order to keep up with expansion, the site began to stock more sub-assemblies. Sub-assemblies take four times as long to manufacture than the final product. Stocking more sub-assemblies means that the final product could be shipped to the customer faster. This increase in inventory has led to space, safety, and quality problems. Inventory physically takes up more space than expected; it is held in nearly every room on site. Figure 3, shows inventory taking up space on the manufacturing floor.

Figure 3: WIP inventory

Operators have experienced an increase in ergonomic issues and injuries due to the rise in inventory. The longer inventory sits, the higher chance it has of contamination; therefore increasing the chance of poor quality product. MilliporeSigma wants to foster a safe, efficient, and high quality manufacturing environment. The company believes that reducing inventory will help achieve this goal.

For this purpose, the company provided a team of Worcester Polytechnic Institute (WPI) students with a charter to guide them to reduce inventory within the facility. A major aspect of this charter was to develop a roadmap explaining how to change the system from a push to pull system. This roadmap will contain a prioritized list of specific actions to make the change to pull manufacturing. The company gave two constraints on the problem. First, customer service levels, final good inventory levels, and the manufacturing scorecard all must either stay the same or improve. MilliporeSigma wants to ensure that any changes made to the process do not have negative impacts on customer service levels. Second, the problem of inventory must not be pushed onto another facility within the supply chain (i.e. distribution centers). MilliporeSigma wants the problem addressed and fixed; not masked or moved. Possible areas to address include interdisciplinary communication, process cycle time, and process failure rate. WPI students will collaborate with MilliporeSigma employees to create this roadmap and decrease inventory. The complete list of MilliporeSigma's requested deliverables for the project is located in Appendix 1.

1.3 Production Process

There are two main types of filters. Single-used filters and multi-use filters. Figure 4 displays broadly the variety of filters produced by the plant.

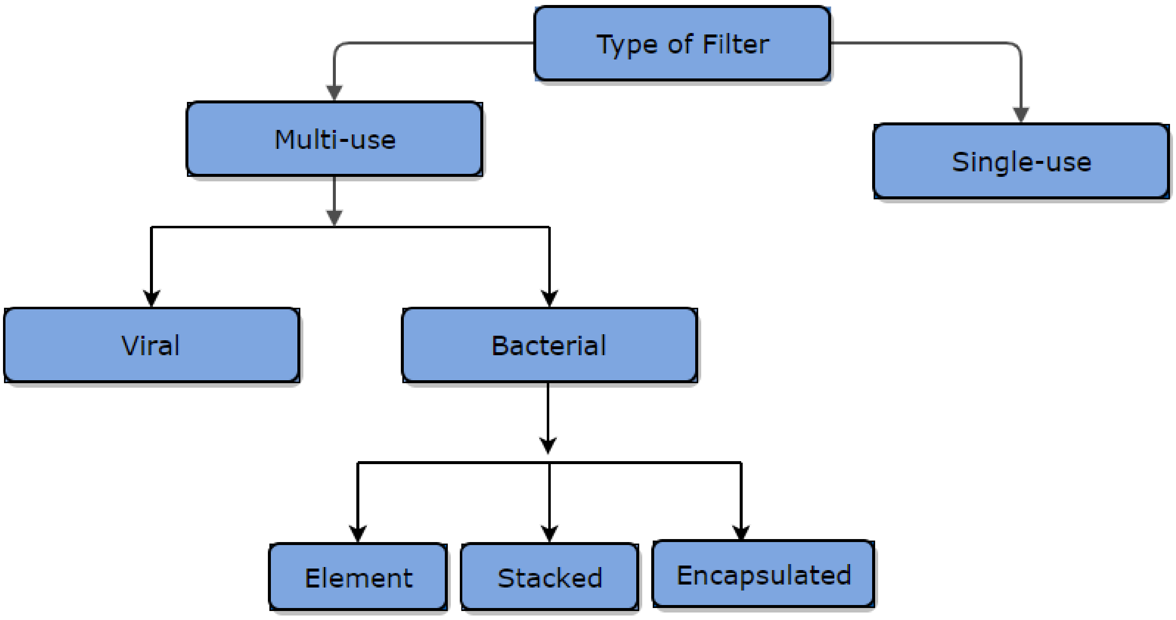

Figure 4: Production Mix

This project concentrates on multi-use, tangential flow filters. More specifically, the project focuses on bacterial retention filters. There are three main different outputs of bacterial retention filters; elements, stacked and encapsulated. Both stacked and encapsulated products are made of elements, which are the main building blocks. An element is the most basic type of filter. It contains a pleated membrane and is capped at both ends. Stacked elements are created by bonding multiple elements using heat. Caps are also bonded to the ends of the unit. An encapsulated product is a product that has been permanently fixed in a plastic housing. Figure 5, gives visual examples of each type of product.

ELEMENT STACK OF ELEMENT ENCAPSULATED

Figure 5: The three (3) product types produced

Approximately 13% of the production leaves the facility and is sold to the customer as an element. 44% of the products leave the facility as stacked units that are sold to the customer. Finally, the remaining 43% of the finished goods are made into encapsulated units.

2.0 Literature Review/ Background

2.1 Inventory Overview

Inventory is a necessary evil. Without it, companies run the risk of not having enough product to meet customer demand. Failing to meet this demand leads to poor customer service rates, backorders, and lost sales. There are multiple types of inventory; the most common is work-in-progress (WIP).

WIP is the sum of all inventory partially completed and currently in the production line. WIP inventory is dictated by margins, procurement costs, and demand level (Jain, et. al. 2013). Reducing and minimizing the amount of WIP is considered a manufacturing best practice. A surplus of extra product can interfere with the process flow and threaten quality standards. WIP should move between work centers one unit at a time; preventing inventory from piling up between stations. Ideally a Lean production environment should contain the least amount of WIP possible (Jain et. al., 2013). In industry, oftentimes companies maintain a higher level of inventory as a safety net to ensure demand is met.

Maintaining a high level of inventory allows companies to meet customer demand at any time. However, companies must decide how much they are willing to pay for this assurance; as high inventory levels come at a high cost. Figure 6, seen below, shows the breakdown of cost associated with carrying inventory.

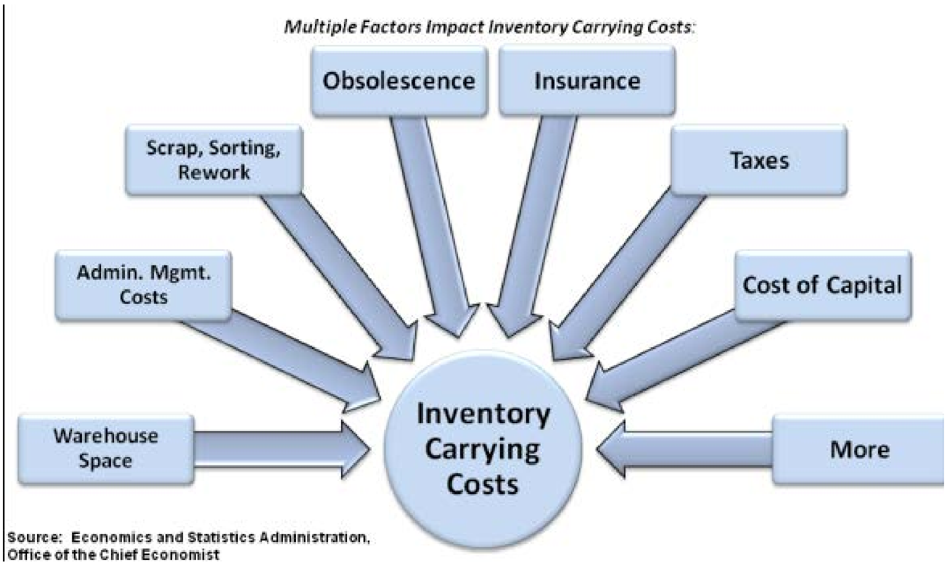

Figure 6: Inventory Carrying Costs

The cost of inventory can be seen in wasted time, space, and money (Silver, 1981). For most companies the financial burden of inventory is seen as extremely challenging. There are three key costs when considering inventory: carrying, poor supply chain, and system control (Saxena, 1969). Carrying costs account for the largest financial burden due to inventory. Carrying costs include warehouse rent, insurance, taxes, and the cost of potential product spoilage. Another key cost is the operation of an insufficient supply chain; also known as backordering. Backordering can have financial and reputational costs due to lost sales and poor customer service. Finally, there is the cost of fixing the system itself which is known as system control. This includes the cost of data and computational analysis as well as the cost of possible negative effects due to the new system.

2.2 Inventory Management

Inventory management, also known as inventory control, is the process of how a company optimizes the amount of inventory on hand to reduce costs (Silver, 1981). Inventory management is an optimization problem meant to meet an objective while following specific decision factors and constraints. There are multiple objectives that a company can choose to accomplish. Common objectives include maximizing profit, minimizing costs and idle time, and ensuring flexibility of the process (Saxena, 1969). Once the objective is set, factors that will impact the objective must be addressed.

Modes of transportation from suppliers and methods of delivery to customers are considered when managing inventory levels. Inconsistent demand patterns require companies to maintain high inventory levels to ensure that enough product is ready to meet demand at any time. Long transportation times also lead to high inventory levels. There are too many factors involved in inventory to individually address them all. It is important to clarify the constraints of an inventory problem so that it does not grow beyond its scope.

Inventory management is often bound by constraints that can be grouped into three categories: supplier, marketing, and internal (Silver, 1981). Supplier constraints are constraints that are imposed on a company by the supplier. These include minimum order sizes, maximum order quantities, or restrictions to certain pack sizes. Marketing constraints are often focused around minimum acceptable customer service levels. Customer services levels are crucial when deciding how to manage inventory. It is imperative that companies keep enough product on hand to maintain customer satisfaction. Internal constraints are constraints dictated by the company. Common internal constraints are space limitations, and restrictions on purchasing budgets per period.

Once all aspects of the problem have been identified there is an array of practices that should be followed to ensure quality results (Silver, 1981). Experts have identified five main practices that increase the likelihood of a positive outcome (Silver, 1981).

1. Attention should be focused on creating a model that accurately represents the system and produces a correct solution.
2. Decisions should be consistent and easy to understand.
3. Focus should be on the aggregate consequences of new decisions. Teams within a company must consider how decisions will affect everyone in the supply chain.
4. New procedures must be understandable. Procedures can be made more understandable through the use of graphs, charts, and visual controls.
5. The behavioral aspect of inventory management must not be forgotten. Operators should be included in the process; they are a good source of information on the process as they perform it daily.

It should be emphasized that the changes to the system are to help the operator, not to replace or punish them. Many successful inventory management techniques have been implemented using these five concepts.

Throughout the years certain techniques have emerged as leaders in the inventory control field. These tools include probability, Bayesian statistics, linear programming, Markov analysis, and queuing theory. One technique that consistently stands out among the others is Lean manufacturing. Lean manufacturing is one of the most commonly implemented inventory techniques. It offers many practical tools to combat inventory problems.

2.3 Lean Manufacturing Overview

The concept of Lean was first introduced by Womack, Jones and Roos in 1991 (Womack et. al., 1991) to describe the working philosophy and practices of the Toyota Production System (Abdullah, 2003). This philosophy focuses on reducing waste and unnecessary tasks that fail to add value from the customer's perspective. The elimination of waste is the basic principle of Lean Manufacturing. Waste is defined as any of the following:

1. Material: Excess raw materials and scrap
2. Inventory: Buildup of material not being sent to the customer
3. Overproduction: Production of products before customers need it
4. Labor: Unwarranted work of operators
5. Complexity: Complex solutions that tend to produce more waste and are harder for operators to manage
6. Energy: Unproductive operations and extra processing
7. Space: Poor layout of work cells and floor
8. Defects: Product made out of specification or of low quality
9. Transportation: Movement of material that does not add value to the final product
10. Time: Long set-ups, delays, and unexpected machine downtime

Lean's main goal is to exceed the customer's expectations by performing at the highest possible level through the elimination of waste. (Demeter et. al., 2011) To eliminate these 10 wastes, Lean has several manufacturing practices. The most common Lean Manufacturing tools are explained in detail in Appendix 2. The success of Lean Manufacturing depends on the application of relevant tools determined by the current state of the system.

2.3.1 Value Stream Mapping

To gain maximum benefits from Lean Manufacturing, one must understand the entire system from raw materials to the end customers. If the system is not understood then problems can go unnoticed and unfixed. Process comprehension can come from experience, teaching the process, or visually displaying the process. In industry, mapping the process is the most used method of understanding.

The most common tool used to visually display a process is called Value Stream Mapping (VSM). VSM is physically drawing out the activities, both value and non-value added, that are required to produce a product. When performing VSM, the owners can choose to analyze the entire process or just a portion. VSM is usually done during a Kaizen event. A Kaizen event is a small meeting attended by the owners and operators of a process to make improvements. Kaizen events can take anywhere from one day to one week to complete. During the event operators and key stakeholders are gathered to map the chosen process. To create a VSM the group gathers data such the process' cycle time, value added time, non-value added time, methods for communicating information, and average downtime. This data is then included in the VSM via figures and symbols. These symbols have been set as standard by the industry and are well known across all fields. Once the process is mapped out using the acquired data, the company can select the Lean practices that will yield the best results.

2.4 Push vs Pull Manufacturing

2.4.1 Push Systems

In a traditional push-based system, a production schedule is developed by a Manufacturing Resource Planning (MRP)/Enterprise Resource Planning (ERP) software and is pushed through the process. The main assumptions in this method are that all variables remain constant and the company has the capacity to execute the plan. As a result, the plan is not flexible and it cannot easily accommodate changes in market conditions (Synchrono LLC, 2014).

A push system begins when senior management sets short and long term financial goals for the company, and thus starts to write the business plan. The business plan dictates the budgets and the goals of the selected period. It then hands the responsibility to the sales, operations, and supply chain departments to determine how these goals will be achieved.

The sales team is in charge of identifying the target market, and inspecting the demand patterns involved with it. They present the information to planners in order for them to analyze the data and find trends. For this purpose, planners commonly utilize forecasting techniques, which don't always represent reality. The operations and supply chain departments then have to make sure that they have the necessary resources to meet the demand set in the master production schedule. They need to account for the inventory status to plan for needed material and they also need to plan for capacity. The simplified process of push planning is described in Figure 7.

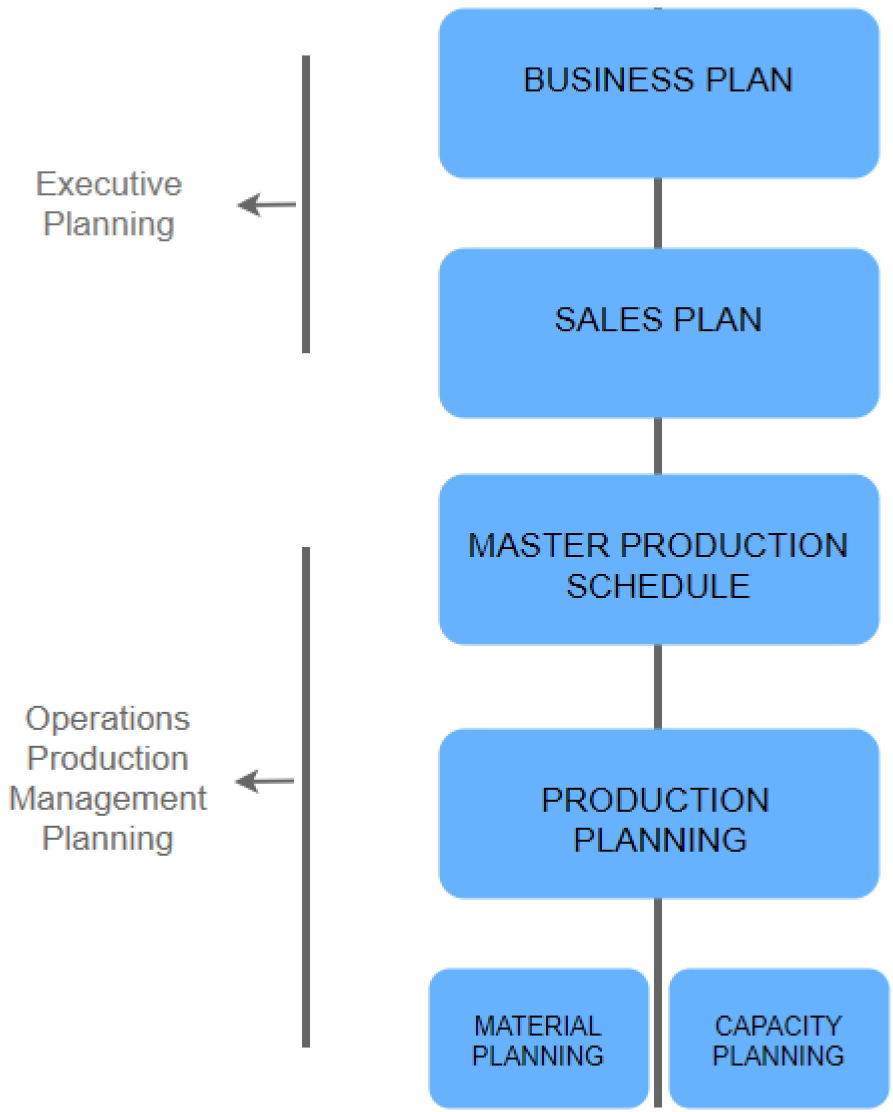

Figure 7: Basic Push Planning (Synchrono LLC, 2014)

The MRP system then needs to be fed with all this information. Inputs to the MRP software commonly include the following:

1. Masterplan: Includes the forecast of demand and the backlog orders
2. Bill of material: States resources needed to achieve the plan
3. Items in stock: Inventory currently held
4. Open purchase orders: Orders which have been issued to indicate prices, quantities and types of products

5. Capacity of the system: Maximum output that a business can produce at a given period with the resources available

This system processes the information that tells machines, people and material what to do, when to do it, and how much is needed. If there is WIP or open orders, there is a great deal of adjustment required to ensure an accurate plan. Variability in customer demand can make this plan difficult to implement. As a result, the push system becomes a cycle which drives increased inventory, lead times and delays. This is portrayed in Figure 8 below.

Figure 8: Push Planning Cycle (Synchrono, 2014)

The perpetual cycle results in excess investment in inventory, overtime, and transportation costs. Worst of all, it compromises quality and directly impacts the customer. Lean techniques provide methods that avoid these issues.

2.4.2 Pull Systems

The pull system is a method for planning, production, and inventory replenishment that allows more control over inventory and product flow. These systems are based on actual consumer demand. Although conceptually simple, the system requires a lot of processes in order to be flexible to changes in demand. It is even harder to establish the system within a company’s culture. These processes involve determining costs, establishing budgets, developing the inventory supplier network and assessing capacities.

The main difference between the pull and push systems is communication between departments (Synchrono LLC, 2014). For example, with the push system, feeding of the MRP is done by forecast data, while in pull systems the consumption of inventory authorizes activity. Activity from cells is authorized when a customer order pulls a finished good from inventory. The signal is then passed from the final stage of the process backwards to manufacturing, and on to suppliers for replenishment. This is achieved by the implementation of different tools (Riika, 2013).

2.4.2.1 Pull Manufacturing Tools

There are a variety of methods that can be used to create a pull system. The three most common techniques are Kanban, CONWIP, and Base Stock Controls. These techniques build upon each other and work to reduce WIP volume. Each technique approaches the problem in a different manner and has its own set of priorities. When choosing a technique it is imperative to consider the process and choose the technique that will best match the system.

2.4.2.1.1 Kanban

The most common tool used in a pull system is the Kanban. This system was developed by Dr. Taicho Ohno, a well-known leader in Lean manufacturing, during his time at Toyota Motors (Guary et. al 2001). In a Kanban system, Kanban 'cards' are used to limit the release of parts into each production stage (Guary et. al. 2001). Kanbans hold a set amount of inventory and are attached to a process that is responsible for keeping it filled. Each step in the process retrieves its production materials from a Kanban. When the Kanban becomes empty, the process responsible for supplying that Kanban starts production. Figure 9 visually portrays a Kanban Process.

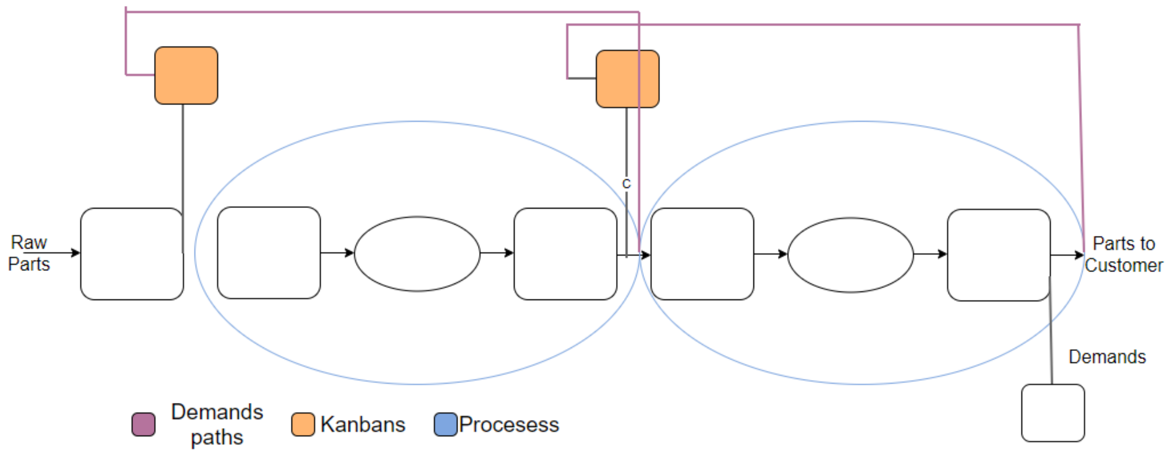

Figure 9: Kanban System (Liberopoulus and Dallery, 2000)

A Kanban system sets up multiple pull systems throughout the entire process. In a Kanban, WIP is easier to control since inventory levels and variability are limited. A part can only be processed if there is an empty Kanban available. This restriction of WIP makes the production system easier to control. Kanbans are also effective because they reduce the fluctuation of demand (Spearman et. al., 1992). The system is not without difficulties. The largest problem is that in upstream stages Kanbans do not respond well to changes in demand (Sharma & Agrawal, 2009). They perform best in a stable environment. Abrupt changes are difficult to handle especially in early stages of production. There are a number of key features that are used to prevent this problem.

A Kanban system requires a number of factors to be effective. First, it needs a smooth production system with a stable product mix. Lead times must be steady and predictable. Unstable lead times make it difficult to determine optimal Kanban levels and prevent Kanbans from being filled in time. An unstable product mix causes a changing system which is problematic. The Kanban system works best when it runs on a precise timeline. Unstable lead times and product mixes make it difficult to fill Kanbans consistently. Second, the process should be as efficient as possible; this can be achieved using Lean tools. Changeover times should be minimized, machines should be in the optimal layout, and work should be standardized. Lean manufacturing lends itself to stable processing times. Kanban systems need to be stable and predictable to function correctly. Third, the process should be constantly undergoing continuous improvement. The process should be constantly improved and problems should be fixed as they appear. Continuous improvement ensures that the Kanban system never becomes obsolete or outdated. Continuously improving the system ensures production accuracy. Fourth, an autonomous defects control system should be implemented (Spearman et. al., 1992). An autonomous defects system automatically catches defective product and signals an alert. This ensures that defective product is handled immediately and does not enter the Kanban.

Having defective product in the Kanban can disrupt the inventory levels and effect on-time production. These conditions are crucial to creating a Kanban system that makes a positive impact on production. The lack of any of the above tools will not prevent the system from running but will decrease its efficiency and effectiveness.

2.4.2.1.2 Manual vs. Electronic Kanbans

Manual Kanban systems use physical Kanban cards for each specified unit of product that is waiting on shelves, pallets, bins, and other holding locations. This card indicates a replenishment signal for that item.

Alternatively, an electronic Kanban (E-Kanban) is a software signaling system that drives the movement of materials within manufacturing, assembly, and warehousing. Barcodes and electronic messages are used to signal for replenishment of material. This allows for automation and thus for accommodation to far more complex situations. Common complex situations include environments with thousands of Stock Keeping Units (SKUs), interplant transfers, overseas locations and large internal and external supply chains. In Table 1 below, a more detailed comparison of the two systems is provided (Synchrono LLC, 2014).

Table 1: Comparison of manual and E-Kanbans

	Manual Kanban	Electronic Kanban
PROS	-Easiest to implement -Used as a Pilot program to test processes and work out the issues -Easier to understand for employees	-Can take several formats such as spreadsheets, packaged software or a Cloud-based application -Barcode transactional systems can handle more complexity -Can eliminate the supply chain bullwhip effect
CONS	-Prone to human error (Wrong manual data entry) -They can be lost or misplaced by employers -Normally have a threshold -Not automated	-More likely to have resistance to change from workers -Sometimes needs additional software

2.4.2.1.3 Oracle's E-Kanbans

Oracle is one of the most frequently used MRP systems. The most recent version of Oracle provides an E-Kanban system. This is a robust graphical user interface that uses barcode scanning and electronic signals to:

1. Eliminate manual entry errors and issues with lost cards
2. Allow real time demand signaling across the supply chain
3. Allow visibility and data integrity across the supply chain
4. Improve the supplier access through iSupplier Portal (Oracle EBS Demos, 2013)

The user starts on the homepage to see notifications that require their attention. Users can view the dashboard that displays inventory health, unmoved cards, actual lead time vs. planned lead time and actual demand vs. planned demand. There are red, yellow, and green indicators which help determine areas that require attention when inventory is below or above optimal amounts. The user can click into the area that needs attention and scroll down into the item card detail. From the detail, the user can make the desired changes to the cards or view cards to take corrective action and bring the inventory to desired levels. This allows users quick identification and access to issues and enables them to resolve inventories efficiently. (Oracle, 2012)

E-Kanban allows for the automatic replenishment of cards based on on-hand inventory. Once the inventory reaches the predetermined amount, the card will be automatically replenished. This is known as “logical card Kanban”. E-Kanban has enhanced planning capabilities where it can plan based on demand from a master demand schedule, master production schedule, forecast, and actual production (Oracle, 2012).

The system can plan and update a pull sequence against demand seen through the horizontal plan. The user can adjust demand and see through a simulation how this affects the system, and decide whether to increase or decrease the number of cards. The system has a default planning formula, however, each company can derive their own formula which best suits their businesses.

The set-up tab is used to build the pull sequence. “Pull sequence” is the definition of how the Kanban is replenished and where it is going to be used. The iSupplier portal is a web based application that provides access to suppliers to view and update demand of the items they supply. Suppliers will be able to update the status of the Kanbans that they are responsible for. They are able to use real time information on their shipments to warehouses. Suppliers have access to view only the Kanbans for which they are responsible. Cards are created for each supplier based on need. This provides the company with current information on the interactions between the plant and suppliers. Current information allows the plant to schedule production in a Just-in-Time manner (Oracle EBS Demos, 2013).

2.4.2.2 CONWIP

The second most common tool to create a pull system is known as CONWIP. CONWIP stands for 'Constant Work-in-Progress'. The objective of CONWIP is to combine the low inventory levels of a Kanban system with the high throughput levels of a push system (Guary et. al., 2001). To do this CONWIP combines the pull of Kanban cards and the push of a traditional production system. Pulls are located at the front end of the system. The raw materials for each stage are released when the final stage signals readiness (Guary et. al., 2001). The final stage signals for the pull of product when final goods are shipped to the customer. Information reaches the first machine directly from the finished item cell (Spearman et. al., 1992). This signal then starts the push of product through the system until it reaches the final good stage. Figure 10 visually portrays a CONWIP system.

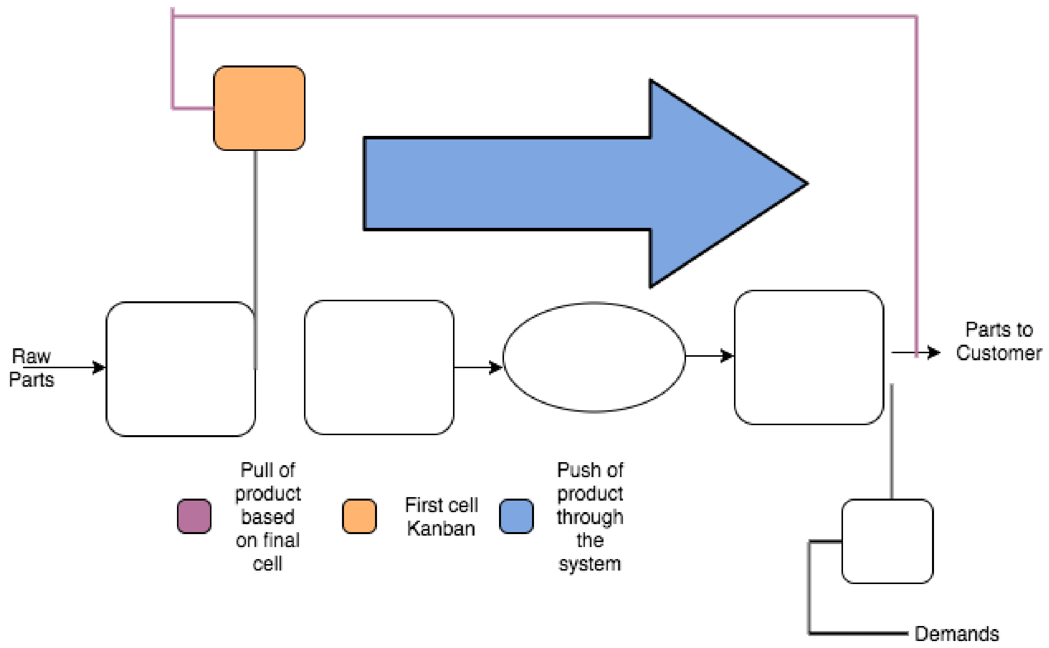

Figure 10: CONWIP System (Liberopoulus and Dallery, 2000)

In a CONWIP system there are significantly less loops than in a Kanban system. Due to this simplicity, implementation is easier and CONWIP can be used in a system with more production stages (Guary et. al., 2001). CONWIP is successful because it limits the total number of components allowed in the system at any moment in time (Spearman et. al., 1992). A CONWIP is a great example of the combination of push and pull systems used to optimize a production system.

2.4.2.3 Base Stock Control System

The third tool used to create a pull system is the Base Stock Control system (BSCS). BSCS was developed in the early 1950's. It is classified under the category of stock control systems and uses information flow to control WIP (Timmer, 1984). In a BSCS base inventory levels are set for all products. These levels are calculated using Echelon stock positions. Echelon stock positions take into account the number of products that have passed through a specific stage but have not yet been sold (Timmer, 1984). These are then compared with reorder levels. Reorder levels are based on product demand to determine base stock levels. In a BSCS production is controlled by the stock levels; this avoids the accumulation of WIP (Timmer, 1984). Customer demand is transmitted to every stage of the system. If there is not enough inventory to fulfill an order or if inventory needs to be replenished production begins for that part. There are no production authorizations in a BSCS; only demand is needed to move product through the system. Figure 11 visually portrays a BSCS.

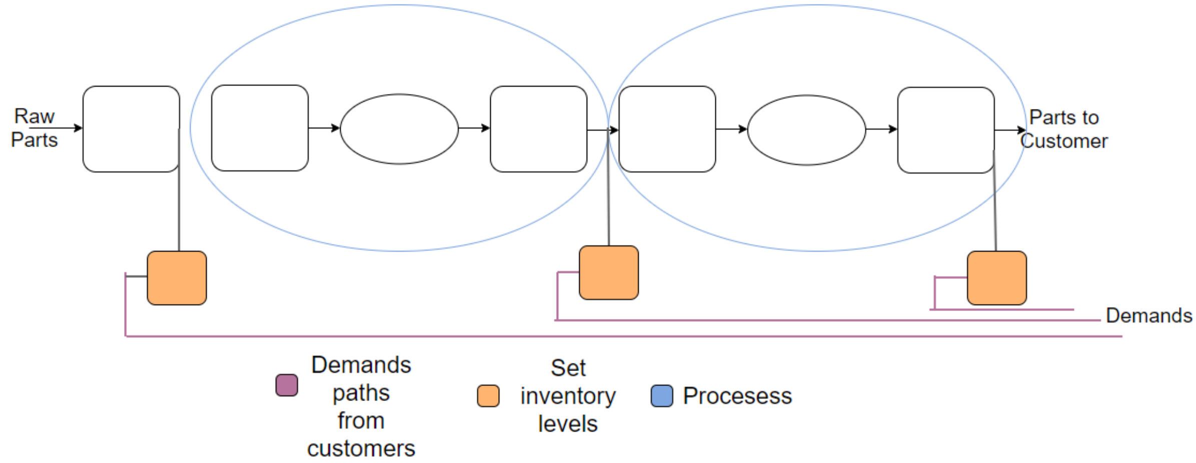

Figure 11: Base Stock Control System (Liberopoulus and Dallery, 2000)

The BSCS has become extremely popular due to its rapid respond to demand. Since demand information is sent to all production stages reaction is nearly immediate. Another benefit of the BSCS is the reduction in WIP due to the set stock levels. This allows the production to be easily managed and flexible. The BSCS does not suffer from amplification effects, or the bullwhip effect (Timmer, 1984). Since inventory replenishment is only triggered by final product demand there is no need to amplify inventory levels throughout the process. One downfall of BSCS is that it must be implemented on all parts in a production system or it will not produce the desired results. Overall, a BSCS is more efficient than a push system because it reduces the need to plan based on forecast and better utilizes safety stock levels.

2.5 Previous Project at MilliporeSigma

In 2015, a group of Worcester Polytechnic Institute (WPI) Industrial Engineering students analyzed the changeover processes at the Jaffrey plant of MilliporeSigma. The aim of the team was to improve the efficiency of changeovers by reducing their frequency and complexity. In order to do this, the team set three main objectives: (1) identify areas of improvement, (2) evaluate and prioritize areas of improvement, and (3) develop and potentially implement three improvement strategies (Delareyna et. al., 2015).

By using methods such as observation and interviews the team was able to identify key areas of improvement. They then proceeded to strategically prioritize these by using the multi-attribute ranking technique SMART. Once the team nailed down the twelve most important areas of improvement, they organized a meeting with the MilliporeSigma team to start an open discussion. Results of this meeting pointed to three specific areas to improve changeover efficiency.

After collecting relevant data from each of these areas, the team designed three improvement strategies. The strategies included the optimization of the production schedule through the Traveler's Salesman Algebraic model, standardizing changeover tasks, and redesigning ‘melt-check’ procedures. The optimization tool was implemented on the critical lines. This tool saved 22 minutes per changeover. The second strategy was also implemented and resulted in a reduction of an average of three minutes per changeover. Finally, the third recommendation was not implemented because it would require substantial changes in management procedures. Due to the success of this past project, MilliporeSigma felt confident reaching out to WPI for help with their inventory control project.

3.0 Methodology

The methodologies outlined in this section were carried out by the team at the Jaffrey, NH facility. To begin the project the group allocated time to background research, getting acquainted with the sponsor, and structuring the overall project. It was decided that the team would investigate how to reduce WIP through the implementation of a pull system.

3.1 Site Visits

The team performed weekly site visits at the MilliporeSigma facility. One day a week was completely dedicated to being on site. Additional visits were scheduled as needed. These site visits focused around the execution of the team's methods and gathering of needed data.

3.2 Observations

The initial method for gaining understanding of the current state and production methods was to observe the various aspects of process. The team observed and studied the processes in the plant and compared them to the Value Stream Map provided by MilliporeSigma (Appendix 3). The majority of time on site was used to observe the operations and interactions of individuals within the facility. The team spent time on the manufacturing floor identifying bottlenecks and frustrations that occur during the process. They not only considered the flow of the product, but the roles of individuals and how changeovers occur. Ultimately, these observations were used to perform analysis so the team could propose effective solutions.

3.3 Simulation

The team created simulation models using a software called Arena. The team created two simulations. The first is the current state model, which includes information from the 2017 Kaizen event as well as the observation and time study data. The second simulations shows the future state of system given all the team's recommendations are implemented.

In the simulations the following assumptions were made.

1. MilliporeSigma's planning process takes approximately 3 days.
2. The facility is operating continuously for 24 hours each day.
3. Set-up time is negligible.
4. Transportation time is negligible.
5. There is always raw material available to produce the required product.
6. Products can always go through rework, meaning no product is completely disposed.
7. Products that must be reworked only go through rework once.
8. Batch size is always 1600.
9. There is no machine downtime for maintenance or any other failure.

Once the team created both models they analyzed the reports and compared relevant metrics. The metrics that were compared are explained in Table 2.

Table 2: Comparable Metrics

Metric	Criteria
Utilization of Resources	To make sure that resources are being used efficiently, and that inventory is not sitting while cells are available for processing.
Length and Waiting Times of the Queues	To identify bottlenecks and re-allocate resources, add or remove resources that might be over or under used.
Time spent in the System	To see how much time can be reduced for a single batch in the future state model.
Work in Progress	To compare inventory in the process and demonstrate decrement of it at the future state model.
Number of units produced	To compare the output quantity in the current state versus the output quantity after recommendations are taken into consideration.

3.4 Time Study

To gather needed cycle times for the simulation the team performed time studies. The team used time studies to gather cycle times specifically in the element manufacturing process. Time studies are also known as ‘time and motion studies’. They were first introduced in the 19th and early 20th century and have now become a common Industrial Engineering tool. Time studies measure how much time is used to complete a job. They show where time is wasted and give a clear starting point for improvement efforts. A time study is often used as a baseline or current state for continuous improvement projects. To ensure the accuracy of the time study the team used four general principles.

First, the team decided what level of detail they want to consider. The team broke the undocumented element process into five stages. The stages included the work cell located at the end of the pleating line, the end capper work cell, the testing work cell, the ovens, and the Accountability department. These stages were defined to keep the desired level of detail and keep the simulation simple. The team recorded the amount of time it took a single unit to pass through each of the stages.

Second, the team explained why the study was occurring to all operators involved. The team explained that the time study was not meant to judge how fast the operator worked. Instead, it was meant to track how much time the process required of the operator. They explained that the time study would not impact the operator’s job. The results would not be shared with the operator’s supervisor or used against the operator in any way.

Third, the team allowed the process to regulate itself before recording the results. The first data points collected during a time study are not representative of the actual work. Oftentimes, the first data points are skewed due to a variety of reasons. The operator could be anxious as they are being timed, the process may need time to ‘warm up’, or the timing could be inaccurate as the process begins. To account for this, the team recorded multiple products going through the required stages. The team then eliminated the first data points and took an average of the remaining. This ensured accurate results and trustworthy data.

Fourth, the team used consistent sampling techniques during the entirety of the study. A standard starting and ending point was defined for each stage. This ensured that no matter who was timing the process the data was consistent. The team also set a standard of one unit to be observed at a time. These consistent techniques ensured the time study produced results that accurately represented the process.

3.5 Spaghetti Diagram

The team used the Lean manufacturing tool commonly known as a Spaghetti diagram. A Spaghetti diagram is used to track continuous motion. It can be applied to paper, people, or products. Spaghetti diagrams visually show wasted motion, transportation, and redundancies in a process. They are a useful tool as they visually show motion in a way that people not directly connected to the process can understand.

The team chose to map the flow of products through the manufacturing floor. They considered the manufacturing floor to include the raw material warehouse, element, stacking, and encapsulation processes. In order to be effective the team mapped the actual flow of the products; not the desired flow. The Spaghetti diagram therefore shows the current state. To map the process, the team acquired a diagram of the manufacturing floor layout from MilliporeSigma’s Industrial Engineers. The team then met with operators that were familiar with the process and mapped out the product’s motion. They did this by drawing a line on the floor layout that directly matched the path taken by the product. The team went to the floor and observed the physical motion of the product to ensure their Spaghetti diagram was accurate. Once complete the team analyzed the product’s motion.

3.6 Interviews

The main purpose of conducting interviews was to further understand the processes through the perspectives of operators and employees. The team interviewed operators, planners, Process Engineers, and other key stakeholders. Interviews focused on material and information flow within the plant. These conversations allowed the team to identify areas of miscommunication as well as to spot the gaps between management and employees. By interviewing the operators, the team gained their insight into daily operations, where they believe difficulties lie, and what they presume could be improved. Furthermore, by interviewing Process Engineers, the team identified the areas with the highest volatility and any variation between shifts and operators.

3.7 Case Studies

The team used case studies to find possible solutions for MilliporeSigma's inventory problem. The team reviewed case studies performed by relevant companies, comparable to MilliporeSigma. Cases where companies faced a similar problem to that of MilliporeSigma were used as a resource. Differences and similarities between MilliporeSigma and the other companies were noted and taken into consideration. Literary reviews of other case studies were evaluated to obtain relevant resources and plans. Case studies were used to take advantage of the work and research done by pre-existing teams at other pertinent locations.

3.8 Value Stream Mapping

The team used visual tools such as Value Stream Mapping to understand the current process and portray their recommendations. The team began with a current Value Stream Map that resulted from MilliporeSigma's Kaizen event in September of 2017. The team analyzed the current map, and used it as a base for their future state map. They added Kanbans and signals to the map to visually show proposed changes. This tool helped the team visually understand the process, identify non-value added steps and critical areas to work on, and gave them a way to easily communicate their suggestions. The current and future state maps are in Appendices 9 and 10 respectively.

4.0 Analysis

4.1 Narrowing Scope

To begin analysis, the team asked MilliporeSigma's planners which products are produced at the highest volume. At the Jaffrey facility the Durapore product line has the highest volume. Of the Durapore products, the team learned that CVGL element-based products are produced most frequently and therefore were chosen to be the focus of the project. In order to further narrow the project scope MilliporeSigma provided the team with data for all of the products in the CVGL element family. The team then sorted the data into two categories: Made-to-Stock and Made-to-Order. After viewing these product lists, it was decided to focus only on Made-to-Stock products since Made-to-Order products should not have a safety stock. Made-to-Order products are not produced as frequently since those parts are not demanded consistently.

The team sorted the products in the tables based on Component Item Number. This was because products with the same Component Item Numbers are built using the same elements. Appendix 4 shows the team's sorted table. Through this sort it was evident that 110605XCVGL elements are make up the highest volume of the Made-to-Stock CVGL goods. The team decided to focus the project around the production of 110605XCVGL element products.

The team then decided to further narrow the scope of the stacking and encapsulation processes. They decided to focus on the highest volume products made from the 110605XCVGL element at each stage of the process. The highest volume products from each stage were found to be CVGL71TP3 from the stacking process and KVGLA2TTT1 from the encapsulation process. These were identified as the highest volume products through the Oracle planning system and speaking with multiple planners. Figure 12 shows how the scope was narrowed.

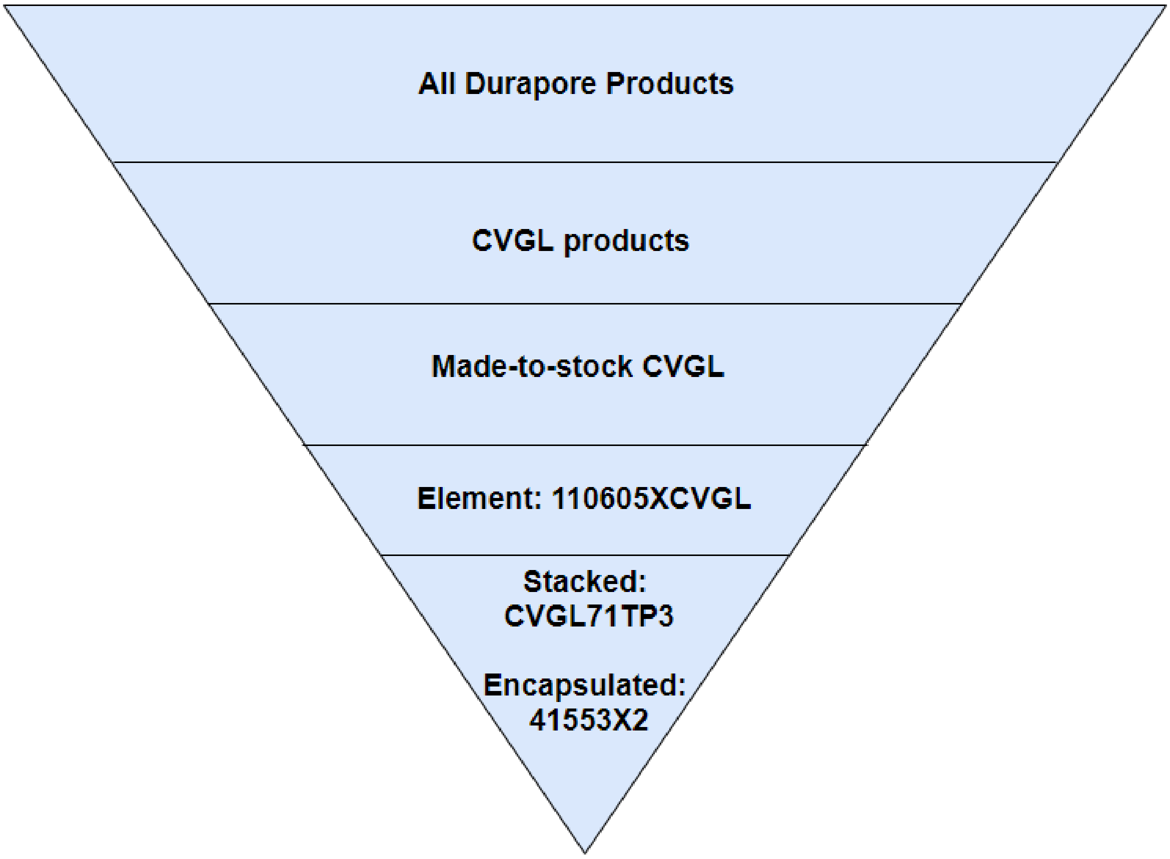

Figure 12: Narrowing of the Project Scope

The highest volume products are those with the highest value. Although these products are not necessarily the most expensive, they are produced in such large volumes that they yield the highest profits for the company.

With a specific scope defined, the team was able to proceed with the analysis of the system. They began by mapping the entire system using flow diagrams.

4.2 Flow Diagrams

The team gathered data about the processes from interviews with planners, floor supervisors, and managers. After these interviews, the team processed the information into flowcharts using software. The first flow chart created portrayed the planning process at MilliporeSigma (Appendix 5). This process is lengthy and encompasses high level planning by the Advanced Planning Optimization (APO) planners, Supply Network Planning (SNP), and Production Planning. The planning is then broken down to elements, stacked, and encapsulated departments. Each department has its own planner. The diagrams helped the team to better understand the communication within the planning department and the information flow. This visual tool helped the team identify non-value added steps and areas of improvement. Flowcharts were also constructed to evaluate the process of manufacturing for elements (Appendix 6), stacked (Appendix 7) and encapsulated products (Appendix 8).

4.3 Value Stream Mapping

The MilliporeSigma current state Value Stream Map (VSM) was provided to analyze and identify areas of improvement. To visually represent the team's recommended future state, a second VSM was created. The team based this future state VSM off of the original VSM. Information that did not change in the future VSM were added directly from the current state VSM. The team then made the needed changes to portray their recommendations.

The most prominent change shown in the future state VSM is the addition of a Kanban system. Kanbans were added to multiple locations within the process. The VSM shows the location of each Kanban, how many Kanbans are to be placed at each location, and what type of product will be held. The future state VSM also shows where in the system product will be physically pulled to the next step via a circular arrow. Appendix 9 shows the future state VSM created by the team.

4.4 Spaghetti Diagram

The team analyzed the continuous flow of products though the manufacturing floor by using a Spaghetti diagram. The Spaghetti diagram is shown in Figure 13.

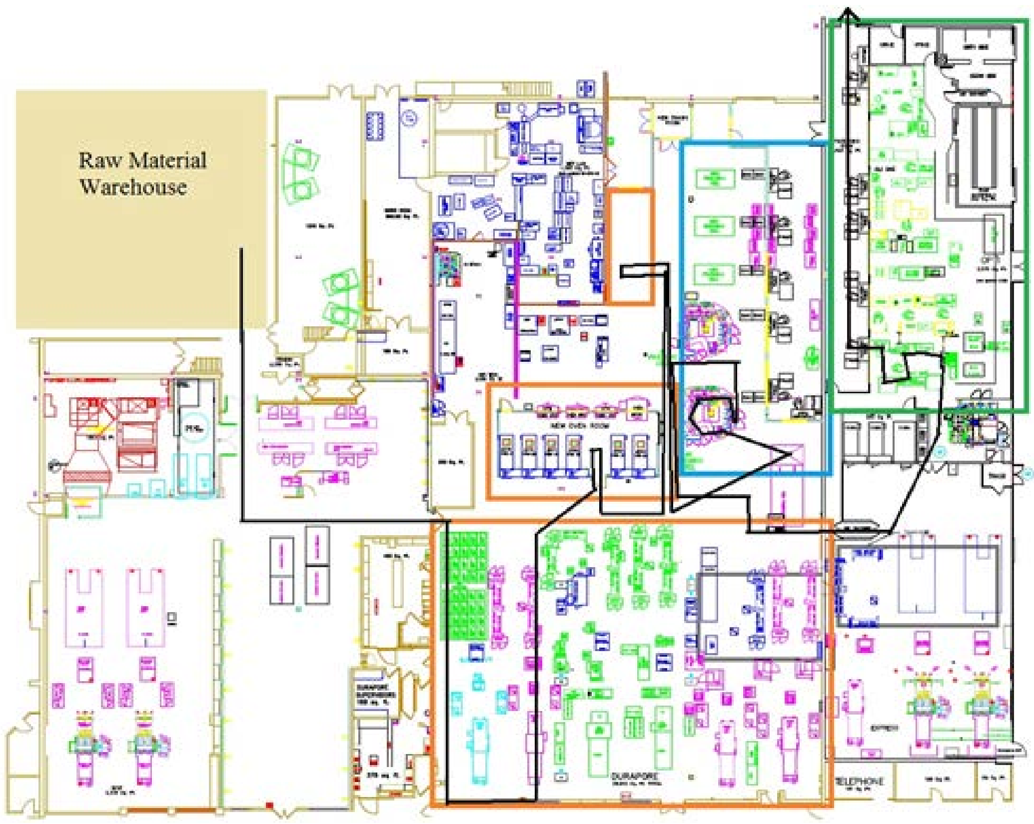

Figure 13: Spaghetti Diagram portraying the flow of products

The colored boxes in Figure 13 are color coded to differentiate the three different manufacturing value streams. The three orange boxes represent the element value stream. This value stream includes the pleating lines, ovens, and Accountability department. The blue box represents the stacking value stream and the green box represents the encapsulation value stream. The products begin the manufacturing process when raw material is delivered from the warehouse. Material then flows through the pleating lines and work cells where it is turned into an element. The elements then are tested and move to the ovens. Once dried, the elements move to the Accountability department where they sit. In Accountability paperwork is checked and quality samples are taken. Product is then moved to the stacking value stream and passes through a work cell where multiple elements are arranged and bonded together. These stacked units then move to the encapsulated value stream. Here they move through the XLT work cell and are placed in housings to be tested again. It is in this work cell that the units are finally bagged and packaged.

The Spaghetti diagram shows that the products undergo the most motion during the element value stream. This is due to the movement from the raw material warehouse and the location of Accountability. Movement of product is reduced in all the value streams by the use of work cells. Specifically in the element and encapsulation value stream work cells are designed in lines so the product easily flows. In the stacking value stream work cells are designed in a circular fashion so products flow within the circle. The majority of motion is due to the transportation of raw materials and movement in between value streams. Overall, the three value streams do an acceptable job of limiting motion.

4.5 Current State Metric Calculation

To quantitatively determine the current state of MilliporeSigma’s process the team identified five key metrics. These metrics were the system’s current process cycle time, current process cycle efficiency, the target process cycle efficiency, theoretical best process cycle time, and the WIP cap. The current process cycle time (PCT) is the time the current process requires to produce one product. This does not include waiting, transportation, or rework. Cycle time only includes the processing time a product undergoes. The PCT was calculated using cycle times from the process current state VSM given to the team by MilliporeSigma. The current process cycle efficiency (PCE) is the portion of the total process that is considered value added to the customer. This metric portrays how efficiently the process adds value to its product. The PCE was calculated using the customer value add time from the current state VSM given to the team by MilliporeSigma and the previously calculated PCT. The target process cycle efficiency was created using a set of guidelines from Steven Bonacorsi "Creating a Lean Six Sigma Pull System", written in 2011. The guidelines are as follows;

1. If the current PCE is lower than 10 percent, then set the target PCE to 10 percent to be conservative.
2. If the current PCE is between 10 and 25 percent, then set the target PCE to 25 percent.
3. If the current PCE is greater than 25 percent, then you can strive for achieving the highest quality target known as World Class. To reach this level you would set the target PCE to the world-class level of 50 percent.

The theoretical best PCT is the best cycle time the process could theoretically obtain. This metric was calculated using the target PCE and the customer value add time from the current state VSM. The final metric, the WIP cap, measures the maximum amount of WIP that can be present if the process is at the theoretical best process cycle time. This was calculated using the theoretical best PCT and the overall process yield rate. Figure 14 shows the calculations for the five metrics.

Current Process Cycle Time (PCT)
PCT=(∑(cycle time (each stage) *total good parts (each stage))
PCT= (6004*5.41)+(4897*1.32)+(2172*2.01)
PCT= 43311.4 min

Current Process Cycle Efficiency (PCE)
PCE=(customer value-add time/PCT)*100
PCE=(666.22/43311.4*100
PCE= 1.5%

Target PCE
Target PCE= 10%

Theoretical best PCT (PCTTB)
PCTTB = customer value-add time/ (Target PCE)
PCTTB= 666.22/ 10%
PCTTB= 6662.2 min

WIP Cap
WIP cap= PCTTB*Yield rate
Yield rate= (yield rate element* yield rate stacked* yield rate encapsulation)
WIP cap= 6662.2* 70.56%
WIP cap= 4700.86 units

Figure 14: Five key metrics

These metrics quantitatively show that MilliporeSigma's current process is poor. With an overall efficiency of only 1.5% the current system is very inefficient. The customer value-add time is very low compared to the cycle time. Only 1.5% of the time it takes to produce a part adds value according to the customer. This value is significantly lower than that of other comparable businesses.

4.6 Simulation

The team created a virtual simulation of the current and future processes using a software called Arena. Appendices 10 and 11 show the Arena simulation. This simulation included the planning, element, stacking, and encapsulation manufacturing process value streams. To create the models the team had to determine the process flow and gather cycle times for all process areas.

The team used a set procedure for defining the process flow in each value stream. The team first met with the subject matter expert for each value stream to physically define the process. These subject matter experts were employees who understood the process and could explain the procedure in detail. Subject matter experts included Process Engineers, shift leads, and process supervisors. The subject experts met with the team and verbally went through the process. During these meetings the team used sticky notes to physically outline the steps of the process. These sticky notes were later turned into digital flow diagrams (see Appendices 5-8). Once the process was outlined the team and the expert went onto the manufacturing floor to walk the process. The team spoke with operators at each stage to ensure the accuracy of the flow diagram. Once the flow was defined the team gathered the cycle times for each step within the value stream.

To gather the cycle times within each value stream the team used two routes. First, the team relied on given information from MilliporeSigma and second they gathered their own information. Given information came from time studies performed by Industrial and Process Engineers in the past. This data was deemed accurate as the time studies had occurred within the past year. The team used multiple methods to gather their own data. They performed time studies, used standard operating procedure documents, and investigated machine settings to gather the needed times. If the team was unsuccessful in gathering data they then turned to operators and supervisors. They interviewed relevant operators and supervisors and gathered approximations of the cycle times needed for the simulation. This method was minimized as it posed the most risk for inaccurate data.

The future state simulation encompassed the team’s recommendations. These recommendations included the implementation of a Kanban system, and additional machines and resources. This simulation was made to compare the team’s recommended state to MilliporeSigma’s current state and see if there was any improvement in specific metrics dictated by MilliporeSigma. These metrics provided a quantitative assessment of the proposed recommendations. An in depth comparison of the current and future state simulations is located at the end of section 4.5.

4.7 Kanban Design

The team strategically chose the places in the assembly line where Kanban signals would be most useful. These locations were based on current WIP accumulation within the manufacturing process. Kanban locations 1, 2, and 3 are in the future state value stream found in the Appendix 9. Location 1 is the area between raw material and the filter production; in this location there would be a Kanban for each raw material. Locations 2 and 3 are between the element and stacked processes and the stacked and finished goods processes respectively.

Once the locations of the Kanbans were set it the total number of Kanbans was determined. To reduce complexity for the material handlers and operators, the team decided to set the Kanban size to the batch size. The team decided that this would cause less resistance to change because it would be easier to adapt. For the element in scope, the batch size is 1600 units. In order to create an initial quantity of Kanbans at locations 2 and 3 the WPI team used the following formula;

'Number of Kanbans = (D*L + S)/C' (Lean Lab, 2015)

"D" is the average demand per period of time, "L" is the lead time in months, "S" is the safety stock amount, and "C" is the standard quantity of product in the Kanban. For the initial number of Kanbans at location 1 the team used the same equation. In this case "D" is the average demand of the raw material per period of time, “L” is the supplier lead time in months, “S” is the safety stock amount, and “C” is the standard quantity of product in the Kanban.

To find the needed inputs for the number of Kanbans at location 1 the team relied heavily on MilliporeSigma’s supplier quality information and bill of materials (BOM). The team decided to narrow the scope for this location to the top three suppliers of raw material for the CVGL line. These suppliers were Fiberweb Inc, Medplast Chicopee, and Polymer Conversions. The team calculated the number of Kanbans for one raw material from each of the suppliers. The metrics needed to calculate the number of Kanbans were found using the CVGL element BOM. The number of Fiberweb Kanbans was found to be 82, Medplast Chicopee was 24, and Polymer Conversions was 101. Figure 15 shows the numerical values, calculations, and results for each of the three suppliers.

Fiberweb	
Part Number	00114767PU-1
Part Description	11" S-Tex Base 30 Spunbonded Nonwoven PP
Amount of raw material per element	20
D=	720900
L=	1.5
S=	1536000
C=	32000
Number of Kanbans=	(720900*1.5+1536000)/32000
Number of Kanbans=	**82**

Medplast Chicopee	
Part Number	108902X4
Part Description	OPTI XLT END CAP BLIND, BRASKEM
Amount of raw material per element	1
D=	36045
L=	1
S=	1500
C=	1600
Number of Kanbans=	(36045*1+1500)/1600
Number of Kanbans=	**23**

Polymer Conversions	
Part Number	15693J
Part Description	PUNCHED TP TOP/STACKING CAP, BRASKEM VMI
Amount of raw material per element	2
D=	72090
L=	1
S=	250000
C=	3200
Number of Kanbans=	(72090*1+250000)/3200
Number of Kanbans=	**101**

Figure 15: Calculation for the number of Kanbans in Location 1

To find the needed inputs for locations 2 and 3 the team used a variety of Daily Report Planning documents and interviews with employees. As a result the number of combined Kanbans in the system at locations 2 and 3 will be 12, see Figure 16.

Number of Kanbans = (D*L + S)/C
D = Average Demand per month
L = Lead time in months
S = Safety stock amount
C = Standard quanitity on Kanban

D = 1290.6 units/months
L = .53 months
S = 17,600 units
C = 1,600 units

Number of Kanbans = (1290.6*.53+17600)/1600
Number of Kanbans = 12 Kanbans

Figure 16: Calculation for the number of Kanbans in Locations 2 and 3

The team found the optimal size of a Kanban location (Navligio et al., 2010) using the ARENA simulation and an optimization software called OptQuest. The team used OptQuest to start the optimization, gather constraints, and give them a clear direction. It is worthy to note that the software malfunctioned, which caused the team to perform some of the optimization by hand. The number of Kanbans at locations two and three in the future state system were optimized based on MilliporeSigma's given objectives. The objectives were to minimize WIP and maximize the throughput of the system. These objectives ensured that MilliporeSigma had on time performance, less backorders, and minimized WIP inventory. The team analyzed all objectives separately to determine the impact the number of Kanbans had on each objective. Scenario 1 was run under the objective that minimizes WIP. Scenario 2 was run under the objective that maximizes throughput. Figure 17 graphically shows the optimization results, while numerical results are found in Table 3Table 3.

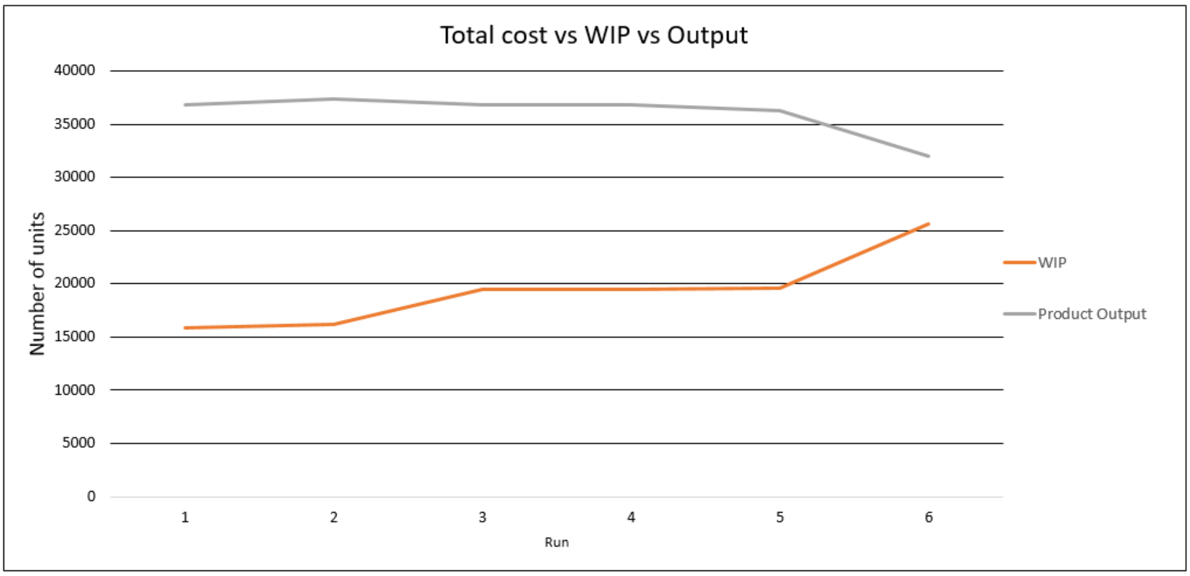

Figure 17: Optimization Results

Table 3: Numerical Optimization Results

	Run	Number of Element Kanbans	Number of Stacked Kanbans	WIP	Total Cost	Throughput
Scenario 1	1	6	6	15911.5	$22,244,277.00	36800
	2	7	5	16177.28	$22,615,834.00	37333
	3	8	4	19492.83	$27,250,981.00	36800
	4	9	3	19492.83	$27,250,981.00	36800
	5	10	2	19645.77	$27,464,785.00	36267
	6	11	1	25599.5	$35,788,101.00	32000

	Run	Number of Element Kanbans	Number of Stacked Kanbans	WIP	Total Cost	Throughput
Scenario 2	2	7	5	16177.28	$22,615,834.00	37333
	1	6	6	15911.5	$22,244,277.00	36800
	3	8	4	19492.83	$27,250,981.00	36800
	4	9	3	19492.83	$27,250,981.00	36800
	5	10	2	19645.77	$27,464,785.00	36267
	6	11	1	25599.5	$35,788,101.00	32000

The team assumed maximizing earnings was the principal objective for MilliporeSigma. As a result the team calculated the earnings for each of the scenarios using the following equation.

Earnings = Throughput * Price of Product - Cost of Carrying Inventory

Earnings Scenario 1 = 36800*1398-22244277 = $29,202,123

Earnings Scenario 2 = 37333*1398-22615834= $29,575,700

Scenario 2 resulted in higher earnings than scenario 1. The difference was $373,577. For this reason, the team selected the Kanban distribution of scenario 2 as the better option for MilliporeSigma to implement.

Once the team found the optimal number of Kanbans for each location, they compared the current MilliporeSigma model with the proposed future state. The metrics compared were WIP inventory, cost of carrying inventory, throughput, and the value added time in the system. Results showed that the future state performed better than the current; Table 4Table 4 summarizes these results.

Table 4: Comparison between Current and Future State

Category	Metric	Current State	Future State	Difference
Inventory	WIP	26,028	16,177.28	-9,850.72
Inventory	Cost of Inventory	$36,387,144.00	$22,615,837.44	-$13,771,306.56
Customer service	Number out	31,143	37,333	6,190
Lead Times	VA time (hrs)	87.77	130.61	41.84

The main objective of MilliporeSigma was to reduce the WIP inventory and the costs associated. The simulations showed that WIP was reduced by 9,851 units when the pull system was implemented. The Kanban system allowed for a 37% reduction in WIP and saved $13,771,306. The customer service levels were evaluated using the overall throughput of the system. It was assumed that the more throughput the simulation showed the less backlog was present, as both simulations ran for the same amount of time. Throughput increased by 6,190 or 19% in the team’s future state. Finally, the team looked into the value added (VA) times, which increased a total of 41.84 hours in the future state. This increase in VA time proved that utilization of the resources is improved after the implementation of a pull system.

The resources are operating for a higher percentage of the total time in system; meaning the product is spending more time being processed rather than waiting. Figure 18, Figure 19, Figure 20, and Figure 21 graphically depict the current compared with the future state metrics.

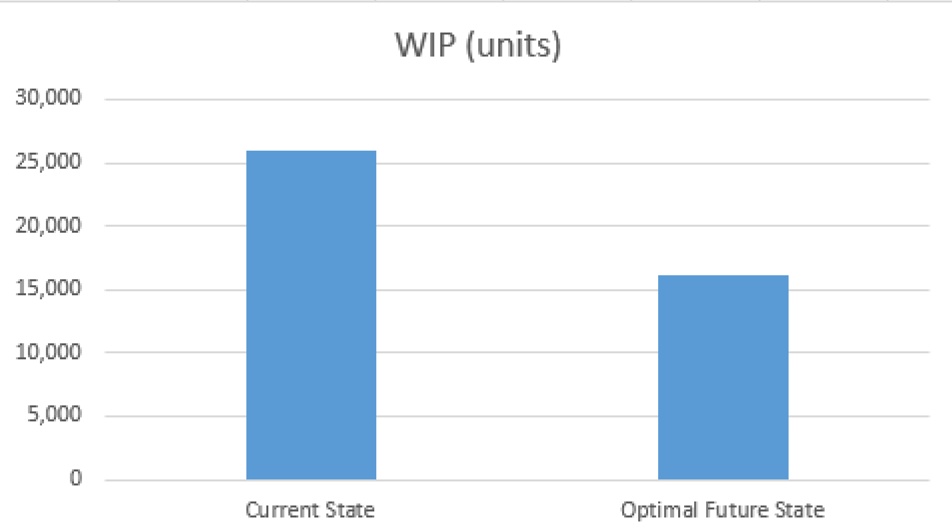

Figure 18: Reduction of WIP from current to future state

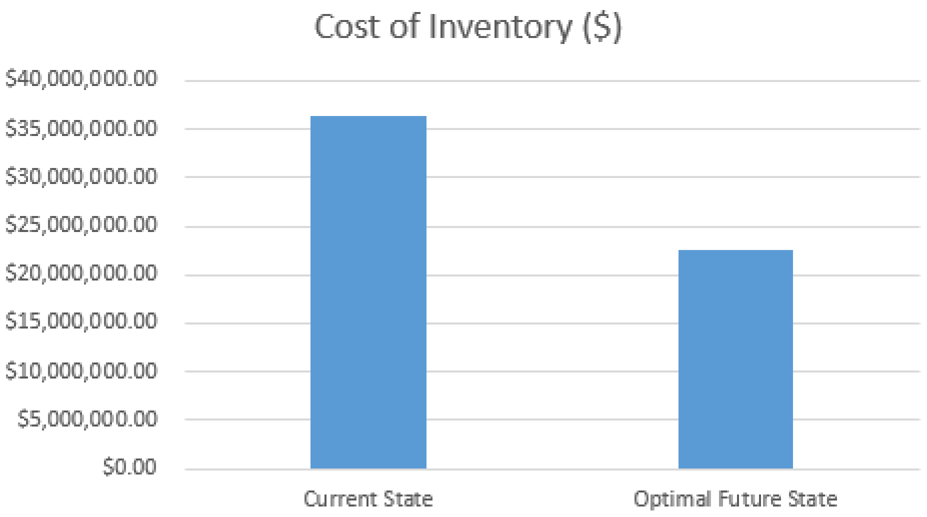

Figure 19: Decrease in Carrying cost from current to future state

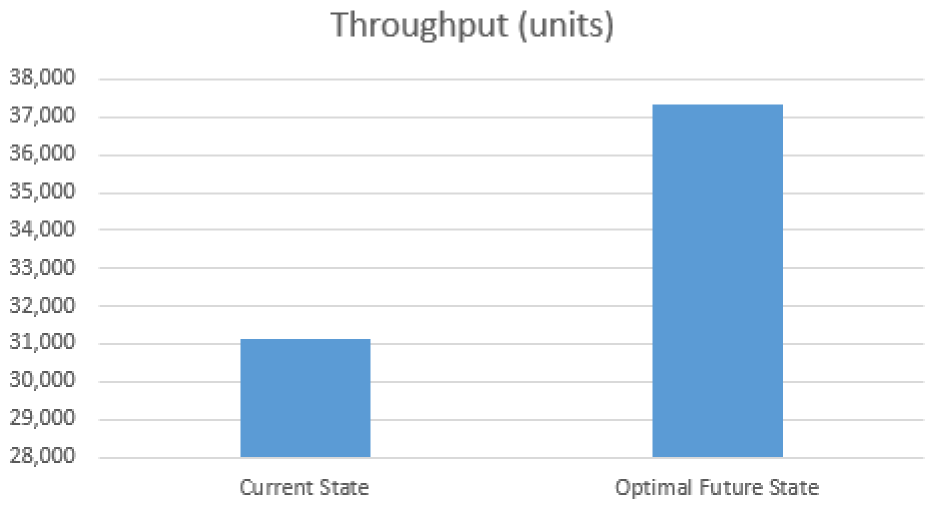

Figure 20: Increase of Throughput from current to future state

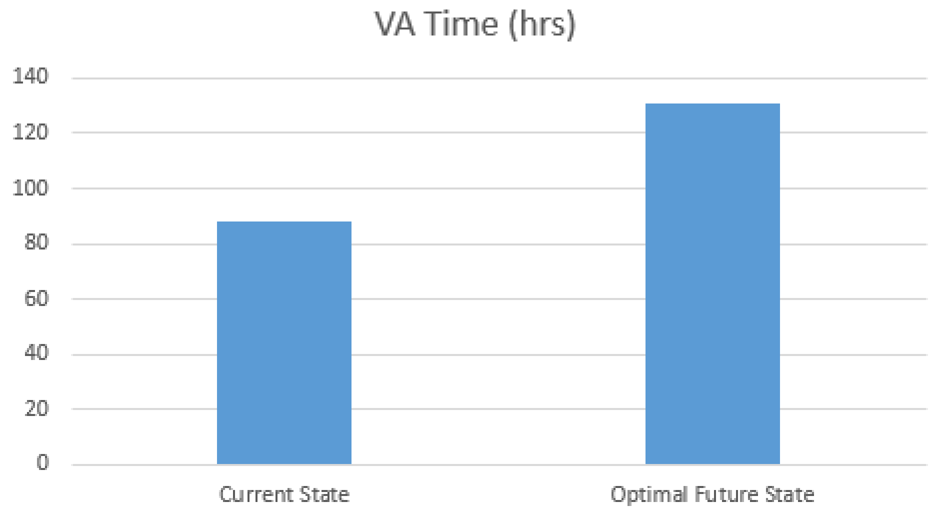

Figure 21: Increase in value added time from current to future state

4.8 Production Plan Strategy Cost Analysis

One of the concerns MilliporeSigma expressed to the team was the burden of inventory at the facility. The team wanted to evaluate the current cost of inventory within the facility for the element (for item number 110605XCVGL) and stacking (for item number CVGL71TP3) stages, where the use of Kanbans is under consideration.

To establish the current state inventory cost the team obtained data from Oracle reflecting the inventory levels at the end of 2017 for the item numbers of interest. A cost of $1,398.60 was assigned to both products as this is the price associated with selling them as a final good. In order to find the total cost of inventory the number of units in inventory was multiplied by the cost per unit. The data for the current state can be seen in Figure 22 below and it was found that the total cost of inventory in the physical current state was $29,090,880.00.

Physical Current State Inventory Cost			
Production Stage	**Item #**	**# of units in inventory (2017 data)**	**Cost**
Element	110605XCVGL	19993	$1,398.60
Stacked	CVGL71TP3	807	$1,398.60

*cost is the same because we are considering the cost of a final good

TOTAL PHYSICAL CURRENT STATE VALUES	
Inventory (units)	20800
Cost of inventory	$29,090,880.00

Figure 22: Current state inventory data for the physical system

Recognizing that inventory levels vary, the team created a simulation of the current state. With the output from the current state simulation the team calculated the cost of inventory as seen in the Figure 23 below. To get the cost of inventory, the number of units in inventory was multiplied by the cost of each unit. The cost of inventory for the current state Arena model was $36,402,760.80.

TOTAL ARENA CURRENT STATE VALUES	
Inventory (units)	26028
Cost of inventory	$36,402,760.80

Figure 23: Current state simulation inventory results

In order to find the future inventory costs, the team utilized the outputs of their Arena simulation. The number of units in inventory was found by using Arena and the cost was assumed to stay the same. The same logic that was used to calculate the current state values was used for the future state.

In order to consider the system's improvements in terms of cost, the team compared both current state inventory costs to the future state model as seen in Figure 24. The future state's savings are shown in Figure 25.

Cost of Inventory Comparison			
	Physical Current State	Arena Current State	Arena Future State
Cost per unit	$ 1,398.60	$ 1,398.60	$ 1,398.60
Inventory (WIP)	20800	26028	16178
Cost of Inventory	$ 29,090,880.00	$ 36,402,760.80	$ 22,626,550.80

Figure 24: Cost of Inventory Comparison

Potential Savings by Switching to Proposed Kanban System		
	Physical Current State	Arena Current State
Current State - Future State	$ 6,464,329.20	$ 13,776,210.00

Figure 25: Potential Savings

By switching to the proposed Kanban system, it is predicted that MilliporeSigma can save anywhere from $6,464,329.20 to $13,776,210.00.

5.0 Recommendations

After observing the current state of the Jaffrey facility, the WPI team compiled a list of identified areas for improvement. Appendix 14 shows a breakdown of the identified problems distributed between three areas of interest: planning, process, and resource. This list was then divided into three categories based on resource utilization and time needed to implement the change: red, yellow, and green. Those problems categorized as red will require the most resources to implement and are long term recommendations. These changes will require significant time and investment. The yellow category signifies medium resource need. These changes require less investment than the red category. Green categorized tasks are low investment and are short term recommendations. These changes need the least amount of time and money. The team recommends MilliporeSigma begin with the changes categorized as green. These changes can be considered ‘quick wins’ for the company.

The first area that will be touched upon are the short term recommendations, followed by the medium and long.

5.1 Short Term Recommendations

5.1.1 Cross Qualify Lines

The product mix demands some flexibility in the manufacturing floor. It is necessary to look into re-allocating resources according to prioritized products, either higher volume, higher variability, higher cost, bottlenecks in the process, and other parameters relevant to the company. The team recommends that lines should be further qualified to keep up with the uncertainty of the production mix.

The team believes that even though this is a lengthy process, in the long run, qualifying lines not only will increase flexibility, but throughput as well. This change will reduce the number of bottlenecks in busy lines and balance the system overall.

5.1.2 Program Pick and Place Robot for One Piece Flow

In the stacking process, the welding machine is loaded completely with elements in each row. This creates a bottleneck when the operator needs to move them from the machine to the operator. The reason for this is that each round of product acts like a large batch (Figure 26).

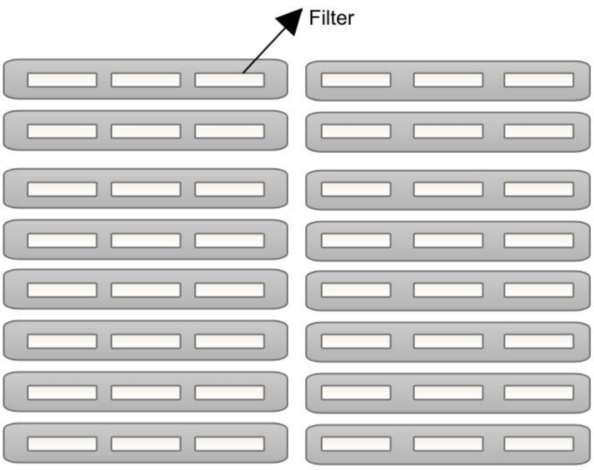

Figure 26: Current machine loading set up

The team suggests that the machine be loaded with two lines of product at a time. This improvement is pictured in Figure 27 where one space for product is left idle every two spaces.

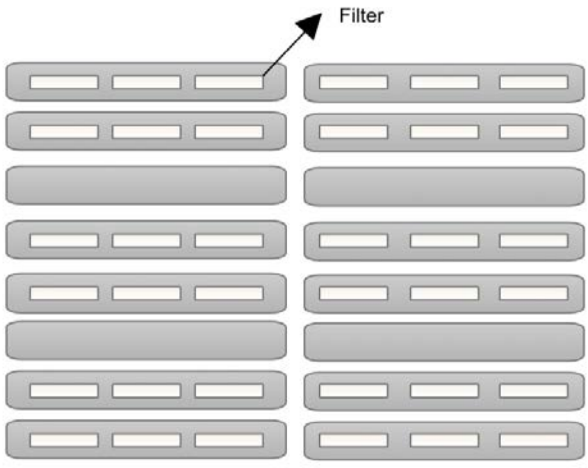

Figure 27: Suggested machine loading setup

Leaving one open space allows for the product to flow continuously and thus drive the whole system closer to a one piece flow. Time is reduced because the operator does not have to load the entire machine before starting the process. The conveyor can start moving once two batches are loaded and the operator can work continuously.

5.1.3 Increase Quantity of Trainers

Through observations of the encapsulation department and conversations with MilliporeSigma employees the team learned more about the distribution of workers on each shift. There are three shifts for the area: A, B, and C. Each shift requires all workers to be certified to run the machines and participate in different parts of the production process.

The B shift is lacking trainers. This means not all employees in this shift are fully cross trained. Cross training more employees on the B shift will increase efficiency and empower operators. The team recommends that MilliporeSigma offers incentives to trainers that assist with educating the B shift employees on a short term schedule. Once the trainers successfully lead the untrained employees of that shift to understand each task, they can go back to working their original hours. It would also be ideal for MilliporeSigma to have a permanent trainer on the B shift. This would create a sustainable training system.

5.1.4 Stop Using Forecast to Plan Made-to-Order Production

Made-to-Order is a manufacturing process in which the production of an item begins only after a customer order has been received. According to planners in the company, they are currently ordering raw material for common and predictable MTO products based on forecast. Even though production is not started until a customer order arrives, this behavior is defeating the purpose of having an MTO product. Having the raw material ready when the customer order is not yet received contributes to the push system and excess inventory.

5.1.5 Update the Oracle Batch Size

After speaking to the planners, the team learned that the batch sizes noted in Oracle do not reflect the numbers that are actually used. For example, when viewing the plan for 110605XCVGL elements in the system, Oracle lists the batch size as 800 units even though planners actually use 1600 units as the batch size. The planners use a higher number than the Oracle value based on their knowledge of yield rates. The team recommends updating the Oracle batch size value to accurately reflect what the planners use. This change will save the planners valuable time and streamline the planning process.

5.2 Medium Term Recommendations

5.2.1 Align Department Goals

Through interviews with employees from various departments, it became clear that not all departments have aligned priorities regarding inventory. Each department has its own set of goals. For example, the Operation department strives to maximize throughput and consistently meet and/or exceed its required absorption credits set by Merck. This means maximizing the daily throughput and producing excess product to meet the period's credit goal. If production is maximized in one manufacturing area and not another the imbalance causes an increase in inventory levels. Producing excess product, even if it is used to achieve a specific metric, increases inventory. Operation's goal is in direct conflict with the Planning department's goal of reducing inventory. The Planning department is currently being pressured from executives to decrease inventory. The department strives to plan just enough product to meet the customer's' demand. With these two goals in opposition of each other, it makes achieving either of them difficult.

Though the goals of each department are valid, forward progress is made only when all departments move cohesively. The team suggests that a set of goals be agreed upon by all departments. These goals should reflect company priorities as well as individual department priorities. If reducing inventory is a high priority then specific goals need to be set for all departments. The WPI team recommends that a cross disciplinary meeting be held with leaders from the involved departments to discuss priorities and to agree upon new goals.

5.2.2 Stop Double Producing Products due to Quality

In the current production process if a lot goes on hold due to quality, the planner will plan to manufacture another identical lot to ensure enough finished goods will be available for the customers. This practice is harmful to the goal of switching from a push based manufacturing system to a pull based system. The team recommends this practice be eliminated and that quality hold system be investigated for areas of improvement.

5.2.3 Add Additional Resources

During observation of the encapsulation process with the floor supervisor it was noted that there is a bottleneck in the processes of cells XL 1, 2, and 3. The bottleneck occurs at the USON testing machine at each work cell. The time it takes to test a single unit is almost twice as long as it takes to produce the unit. This leads to two issues. First, a buildup of product right before the USON testing machine and second underutilization of encapsulation machines. Adding another USON testing machine to cells XL 1, 2, and 3 would increase the throughput of these cells and allow for smoother production flow.

XL 4 is the only cell that currently uses two USON machines and is not suffering any bottleneck. The supervisor and multiple operators agreed that XL 4 has the highest throughput of all the cells. They agreed that this is due to the extra USON machine.

The impact this change would have on overall inventory levels is estimated to be minor in comparison to other recommendations. It was noted during the Gemba walk that the USON machines were a recent, expensive purchase and that executives are hesitant to purchase more so quickly. These reasons have lead the team to categorize this recommendation as a low priority. The team is certain that if implemented this recommendation would cause visible improvements and lead to production efficiency in the encapsulation process.

5.3 Long Term Recommendations

5.3.1 Implement Pull system

According to the team's observations, the Planning and Manufacturing departments are currently a push system. The WPI team recommends that MilliporeSigma transform their manufacturing process into a pull system using the Kanban system design. The WPI design provides locations for the Kanbans, quantity of Kanbans per location, number of products per Kanban, and visual signals to ease the use of these Kanbans. Based on models comparing the use of push and Kanban systems within MilliporeSigma, several parameters would improve if the company used the team's Kanban design.

5.3.2 Investigate Quality

Although the Quality department was out of scope, the team observed that there are many factors influenced by Quality within the Jaffrey facility. Since there is a high quality check requirement, product lead times are greatly affected by Quality processes and holds. One of the main overproduction problems stems from the uncertainty Quality adds to the system. Quality holds coupled with long lead time causes uncertainty that orders will be shipped to the customer on time. To combat this when a batch gets held up by Quality, planners schedule another batch identical to the first to produce enough product to meet customer demand. If Quality became more predictable the facility would be less likely to overproduce and therefore reduce their WIP inventory.

5.3.3 Change from Oracle to SAP

In 2010, the Millipore Corporation was acquired by Merck. Prior to the acquisition Millipore has been using a system called Oracle to track their inventory while Merck uses a different system called SAP. Millipore continued to use Oracle even after the acquisition. Since the parent company is utilizing a different planning system, steps had to be put into place to transfer the data from SAP to Oracle.

Unfortunately this transfer is usually inaccurate. Each morning an email is sent to indicate how trustworthy the converted data is by using red, yellow, and green ratings. Green means that the data is trustworthy and can be used with limited caution. Yellow indicates a need to be cautious as data may not be the most accurate. Red means that the data cannot be used in its current state and needs to be completely reworked to accurately reflect current forecasts, orders, and demand.

Regardless of the color rating, planners need to take time and check the data to make sure it reflects current demand accurately. Planners use the annual projection metric to identify errors in the given data. If the annual projected demand drastically increases or decreases within a day, it is evident that the data is not accurate.

In order to resolve the problems caused by converting the data from SAP to Oracle, the team recommends that MilliporeSigma switch to the SAP system that their parent company uses. The team knows that this option has been explored in the past; the project was put on hold by the acquisition of Sigma-Aldrich because the new company had a different version of the SAP system. This caused Merck to explore the option of upgrading their system; putting the Millipore software update project on hold. Now that Merck has settled on using their current version of SAP, the team recommends that MilliporeSigma reconsider changing their software. An efficient planning process reduces the chance of error and enables a more effective pull system.

The team is conscious of the cost and timeliness that it would take to change a whole software system in a company. This would not only imply a huge cost on the company's budget but also a significant amount of time to implement it correctly. As a result, the team wants to emphasize that even though switching from Oracle to SAP is a priority that the company needs consider, there are other options that can be used to improve the current performance of the system.

5.3.4 Fix Planning Issues in ORACLE

Planners at different stages of the process find the need to repetitively edit the reports every day because of inaccurate data. Planners agreed that the Distribution Requirements Planning (DRP) is not efficient because the report ignores four important factors. These missing factors are seen in Figure 28.

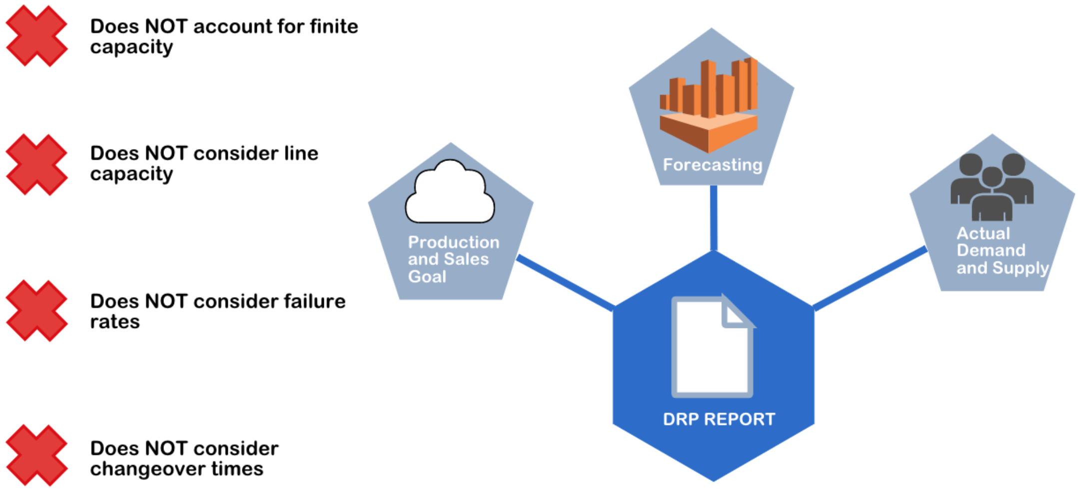

Figure 28: Problems in the Oracle system

The fact that the DRP system does not consider overall capacity has a big impact on inventory buildup, causing planners to smooth. Smoothing is when planners assign products to different lines to be able to keep up with the required demand schedule, even though these lines are not prepared for such production. Smoothing also involves shifting timelines in order to account for the schedule of certain products. Smoothing most often occurs during element planning, but it is not limited to only this area. The team recommends that MilliporeSigma update the code in their Oracle software to account for finite capacity, change over times, line capacity, and yield rates.

5.3.5 Increase Forecast Accuracy

The current forecasts given to MilliporeSigma's planners are unreliable at best. Inaccurate forecasts are the leading cause of excess inventory. Multiple planners expressed their frustration in "not being able to trust the data given to them by their own system". One planner explained to the team that it is common to plan based off a particular forecast one day and go back and see the forecast gone completely or drastically different the next. Currently, the forecasted product mix accuracy is only 60%. This means that planners cannot trust the product mix of the predictions given to them. It is common to have the product mix change multiple times per period. This makes planning accurately and in advance extremely difficult. It is impossible for planners to plan at least a week in advance when the forecast they receive changes daily. When forecasts are obviously inaccurate planners look at supply and demand levels directly. This causes the planning process to lengthen and adds more opportunity for error. It is extremely common to have a schedule go to production and have the forecast change last minute. At that point, the schedule cannot be altered and production must continue. This leads to either excess inventory or the inability to fill an order.

In a true Pull manufacturing system, production is based entirely on customer demand. Forecasts are never used. The team recognizes that this is not always feasible due to long lead times and unpredictable demand. When it is necessary to use forecasting the information provided must be at least semi-reliable and consistent. MilliporeSigma can increase its forecast accuracy by reviewing and updating forecast models, requiring customers to order product further in advance, and by investigating why the forecast is currently so inaccurate. The team recognizes that many of the forecasts come from the corporate level. Though this may not be in MilliporeSigma’s scope it would be highly beneficial to improve forecasts. This issue is affecting all areas of planning. If improving this issue is deemed impossible at the time, the team recommends elevating this problem to the next level of executives.

5.3.6 Eliminate the Possibility to Request Single Lot Orders

In the current process customers have the ability to request to purchase orders from the same lot. MilliporeSigma greatly values customer service and satisfaction so they go out of their way to accommodate these requests. Meeting these requests and producing a single lot for a customer, especially when there is plenty of safety stock available, adds to inventory levels. Since the goal is to reduce WIP through the implementation of a pull system, this method of creating a Made-to-Stock product as Made-to-Order creates more inventory. The team recommends that MilliporeSigma stop accommodating these requests and communicate changes to the customers.

5.3.7 Reevaluate Absorption Credits System

A goal of the current operation is to meet the absorption credits metric set by Merck. This metric allows Merck to keep track of the income per period and efficiently manage their balance sheets. At the end of the period, the Operations department will produce more inventory than what can be sold, in order to meet or exceed this metric. The application of the credits is misunderstood across all areas of the facility. Each person the team asked had a different explanation for how these credits worked. Overall the absorption credits system is seen as a method of considering cost of inventory as the cost of goods sold. This interpretation is flawed as the cost of inventory does not increase a company's retained earnings until it is physically sold to the customer. Only then can the cost be added to income. Counting inventory as cost of goods sold is detrimental because it leads to an unnecessary increase in inventory.

The team recognizes that changing the absorption credits may be out of MilliporeSigma’s scope. However, the team recommends addressing this issue as it is a significant source of excess inventory. The team highly recommends that the company educate employees about the meaning of this concept and how it is applied within the facility. Confusion can cause misalignment of goals and chaos.

The team hopes that MilliporeSigma will consider these recommendations and look into implementing them. By making these improvements MilliporeSigma will have the opportunity to enhance their current inventory management system and ability to satisfy customers.

6.0 Conclusion

In this Major Qualifying Project (MQP) a team of three Industrial Engineering students from WPI worked with MilliporeSigma to define a system for pull manufacturing. The team looked at the manufacturing process starting with raw material kitting and ending with finished goods manufacturing. They looked at the front-end and back-end of the current system critically to identify flaws and areas of improvement. Based upon the identified areas of improvement the team created a prioritized list of recommended changes to the system; also known as the “road map”. This road map was prioritized by the resources required for each change. Changes that required few resources were recommended to be implemented first while high resources were recommended to be implemented in parallel. The team developed a Kanban system that would convert the manufacturing system into a pull system. They created a numerical model for calculating the number of Kanbans at predetermined locations that included safety stock levels. Finally, to compare the team's recommendations with MilliporeSigma’s current state, simulation modeling provided a quantitative impact assessment. During the project, the team faced one major problem. The optimization software, Optquest, did not work fully and the team had to finish the optimizations by hand. In the future, the team would chose to use a more current optimization software.

If MilliporeSigma choses to implement the team’s Kanban system and changes the team recommends two actions. One, MilliporeSigma should reach out to customers to educate them of system changes. Only a few of the changes impact the customer directly; the majority of the team’s suggestions impact them indirectly. The changes will only effect on time delivery metrics, not product quality. In order to avoid angry customers, MilliporeSigma should communicate their changes with them and give an explanation for the possible delays. Two, MilliporeSigma should follow the road map's timeline exactly and perform the suggested changes in parallel. The road map was constructed in a manner that makes the changes easier for MilliporeSigma to implement. By following the road map MilliporeSigma will reduce the time and cost of upgrading their system. The team recommends MilliporeSigma implement the given Kanban system and suggestions into their manufacturing system to turn it from a push to a pull system.

7.0 Reflection

Our main deliverable was an instructed approach to transform the current production system from a push to a pull system. The approach divides into two parts: a road map and a Kanban system design. The road map contains suggestions to stabilize the manufacturing environment and to smoothly convert it to a pull system. The Kanban design includes a new value stream map with Kanban locations, Kanban quantities per location, Kanban sizes, and signals for communication across the plant.

The objective of this design was to reduce WIP inventory. Evaluation criteria was used to quantitatively show improvement. Criteria included key performance indicators' set by MilliporeSigma. In order to provide affective deliverables, we immersed in the company by observing and quantifying several factors. Once company's current situation was understood, we were able to construct two simulations using software. The first mimicked the current state of the plant and the second provided evidence of improvement in the recommended state. We then proceeded to test the model to find the optimal number of Kanbans per location. The objectives were to minimize WIP inventory and to maximize throughput. To compare these objectives, we tested each objective's earnings. Once the optimal amount of Kanbans were found, the future state model was tested and evaluated against the current state. The results consisted in evaluating four main metrics. These were WIP inventory, inventory cost, throughput, and value added time. Results found that the future state improved the metrics.

The constraints considered in the design initiated from the project charter that was provided to the team by MilliporeSigma. Key considerations included health and safety, ethics, manufacturability, sustainability, and customer service. While conducting their research and producing their deliverables we maintained awareness of the key considerations.

In terms of health and safety, MilliporeSigma wanted us to focus on increasing the safety of their employees while also considering the customer. Due to the amount of WIP in their system MilliporeSigma was getting to the point where all space not allocated to their employees held inventory. This was a major concern for both the team and MilliporeSigma as it restricts employees to tight quarters. The other aspect of health and safety considered was the consumer. Since the Durapore filters we were considering are used for life science applications it was extremely important to consider the integrity of the product. We needed to consider the effects of our recommended implementations on the quality of the filters themselves.

The ethics of our work was the primary driving force in our decisions. Everyone on our team holds ourselves to a high standard of ethical work and wants to ensure that the recommendations made have a positive impact of all of those involved with MilliporeSigma. We valued our relationship with the sponsors and strived to help them improve their processes as well as customer relations.

Manufacturability was a focus of our project, not in the sense where we have created a product to be manufactured, but how to effectively manufacture the current Durapore CVGL product line. We worked to understand the current manufacturing process through informational interviews, Gemba walks, time studies, and creating flow diagrams. At the beginning of the project we were also provided a value stream map that we frequently referred to in order to understand the current process more. With a main objective to transition production from a push to a pull system manufacturability relates to many of our deliverables. Through the recommendations in our road map and Kanban system our goal was to improve manufacturability while reducing WIP. Through our suggestions the manufacturing process would become more predictable and reliable.

Our primary consideration while completing this project was the sustainability of our recommendations. We strived to create realistic and viable recommendations. Many of our ideas came from direct observations and interviews with employees. We wanted to prioritize issues that were brought up by multiple individuals and areas. For example, overproduction of certain products was brought to our attention by both planning and manufacturing employees. We took time to analyze possible root causes and explain the reason behind the need for changes to be made

The final constraint considered was customer service. From the beginning of our project one of MilliporeSigma’s primary considerations was the impact our deliverables would have on customer service. They made it extremely clear that it was key to either maintain or increase the current customer service levels. As individuals we all understood the need to keep the customers satisfied.

All of these constraints were handled in the design alternatives. When creating our final recommendations we wanted to make sure we balanced all of our constraints to make the most effective impact on the manufacturing process. We understood that although we were provided with the instruction to consider a push to pull transition there are other factors involved.

In this project we used many different disciplines. We used Industrial Engineering, business analysis, project management, product development, and modeling techniques. Though the majority of our actions were led by Industrial Engineering, business analytics was very present in this project. We used business analytics tools, such as cost and scenario analysis, to critically look at our recommendations and determine their feasibility and ease of implementation. We considered our deliverables to be the ‘product’ in this scenario and used product management techniques to create deliverables that were of the highest quality. We used many modeling techniques including quantitative modeling and simulation modeling. These supported our recommendations with quantitative data. The marriage of concepts across disciplines allowed us to create well rounded and feasible deliverables for our sponsor. Overall our recommendations include aspects that would have an impact on all areas of the Jaffrey plant and even some external factors such as the warehouse and end customers.

7.1 Luciana Alvestegui

Being able to be part of this huge company with such a complex problem was of great value to my learning experience. As an industrial engineer student, I have learned a lot of inventory and inventory management in class, but I had never seen it in a real life situation. Not only does the company have an immense problem with inventory control, but also with communication and people factors. I have learned that the world is much more complex than what they show you on text books and it is a matter of not only mastering concepts, but also being able to listen, pay attention to every detail, observe, measure, analyze, research and think out of the box. Many concepts that I learned through my career could be applied to this problem. However there is always more to learn, more research to be done and more room for error and misguidance in real life.

I personally think that to continue the learning endeavor, I have to continue to open my mind to other types of thinking, get out of my comfort zone, experience new things, and always challenge myself to learn more and to find better solutions. There is always room for improvement, no matter how big or small this might be. A company, as huge as MilliporeSigma appreciates any contribution because any reduction in their inventory would escalate into big savings. I think any company has such problems, so it is a matter of compromising with a company and doing the best to fulfill their expectations. In this way not only they win, but I also win by being able to learn from a different culture and work environment.

The design itself was not made by using computer programming, but it would have helped a lot to know more of this area to be able to better optimize the quantity of Kanban per location. Also current technology and information systems in the company seem to be the major problem since data is getting transformed and mislead through the process. Further analysis could be done investigating on how to make Oracle (their inventory control software) more reliable and efficient.

Financial considerations could also be further investigated if the company were considering on changing the layout, adding machines and redistributing capacities. A cost-benefit analysis could be performed if more machines were added. For example we suggest to add one extra USON machine but we were not able to get into details to support that this would ultimately generate more gains and how long would it take for the investment to pay.

Finally there is always the opportunity cost analysis that concerns every business. For example we also suggested that the company establishes to their customer certain rules for ordering. (Only sell lots, not separate products) This could in some ways be negative for service levels. The analysis could be to evaluate to what extent this could hurt the service levels and if it compensates with the benefits.

7.2 Renée Laliberte

This MQP project allowed me to gain valuable knowledge about both myself and the field of Industrial Engineering. In terms of Industrial Engineering I really enjoyed gaining experience in dealing with ‘real world’ problems where there are more aspects to consider beyond the numbers behind a situation. I enjoyed piecing together the human aspects of the project with the engineering goals defined. In every system there are people involved and I found it satisfying to consider how our project will impact them. Through this project I learned that I personally found the manufacturing interesting but especially valued the people of the process. Without considering those directly impacted by the problem at hand one truly cannot make any improvements. This has lead me to the realization that my Industrial Engineering degree has provided me with much more than just a technical education.

The most unexpected part of working on this MQP was the amount of change that occurred throughout the course of the work. Initially the project was introduced with a goal of reducing inventory by 30%. We began our work by observing and gaining understanding of the current processes. Since the goal seemed extremely vague and large to take on we initially struggled to find direction. A month or so later a new project goal had been defined and presented to us as the ‘new’ focus of our project. These goals were outlined in the charter seen in Appendix 1. I remember initially being confused and frustrated by the sudden change in direction. As the project progressed and we understood more of the processes under consideration I realized that the updated project goal was actually very helpful. It helped solidify key deliverables to focus on and helped lead us to establishing a project of manageable scope. This taught me that although expectations may change, it is not impossible to adjust and the changes may be for the better.

Working on this project has forced me reach outside of my comfort zone in multiple areas. Just because this project was defined as Industrial Engineering does not mean that is all we focused on. Other aspects of the project included project management, business analytics, modeling, and product development. All of these areas needed to come together in order to reach the goals and objectives outlined by MilliporeSigma. The overarching goal of the project was to reduce WIP and increase throughput within the facility and without considering the goals of individual departments and their functions it would have impossible to achieve positive results. Though this project it was extremely evident that in order to be successful within industry one must be willing to not only collaborate with other areas, but also submerged themselves into another discipline.

I enjoyed having the opportunity to apply my classroom knowledge to the industry. It was a positive experience to learn how to develop within a business setting and handle a real problem.

7.3 Naomi Phillips

This MQP proved to be an educational and worthy experience. I not only learned more about Industrial Engineering but I also learned about business practices and what it is like to work in a professional setting. This project was not without its difficulties and frustrations. In the start of B term the project underwent a change that left the team without a clear direction. During the duration of the project (especially in the beginning) it was extremely difficult to gather data, schedule meetings with people, and get direction from MilliporeSigma. I feel like the majority of my lifelong learning experiences came from these frustrations. This MQP taught me how to manage frustration in the professional setting and how to make the best of difficult situations. I learned how to work with difficult people and departments and how to advocate for my project. These are skills that I will continue to build upon and use in my future career. I will always have to work with difficult people. I will continue to learn different tactics and skills to make the best of these situations. I will continue learning from those who take the time to help me by asking questions and applying their answers.

Our recommendation takes into account the social factors of MilliporeSigma’s workplace environment as well as the manufacturing culture. We took into account the way MilliporeSigma currently runs as we developed our deliverables to ensure that none of our deliverables would oppose their values and culture. We spoke with employees both on the manufacturing floor and in the offices. We gave specific recommendations of when actions should be taken to make the changes as easy as possible for MilliporeSigma to implement and adapt to. We made our recommended changes gradual so that they would have a higher chance of success. Though this project was labeled an “Industrial Engineering” MQP, a variety of disciplines were used and the team learned about much more than just Industrial Engineering.

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9.0 Appendix

Appendix 1: MilliporeSigma Project Definition and Deliverables

Project Definition: Define a system for pull manufacturing from raw material kitting, element manufacturing, QC testing, Finished Goods manufacturing, and QC/ lot release

Deliverables: Recommend the modeled production pull system from F/G manufacturing through material kitting for element manufacturing (limited to areas where WIP and Lead time reduction opportunities exist).

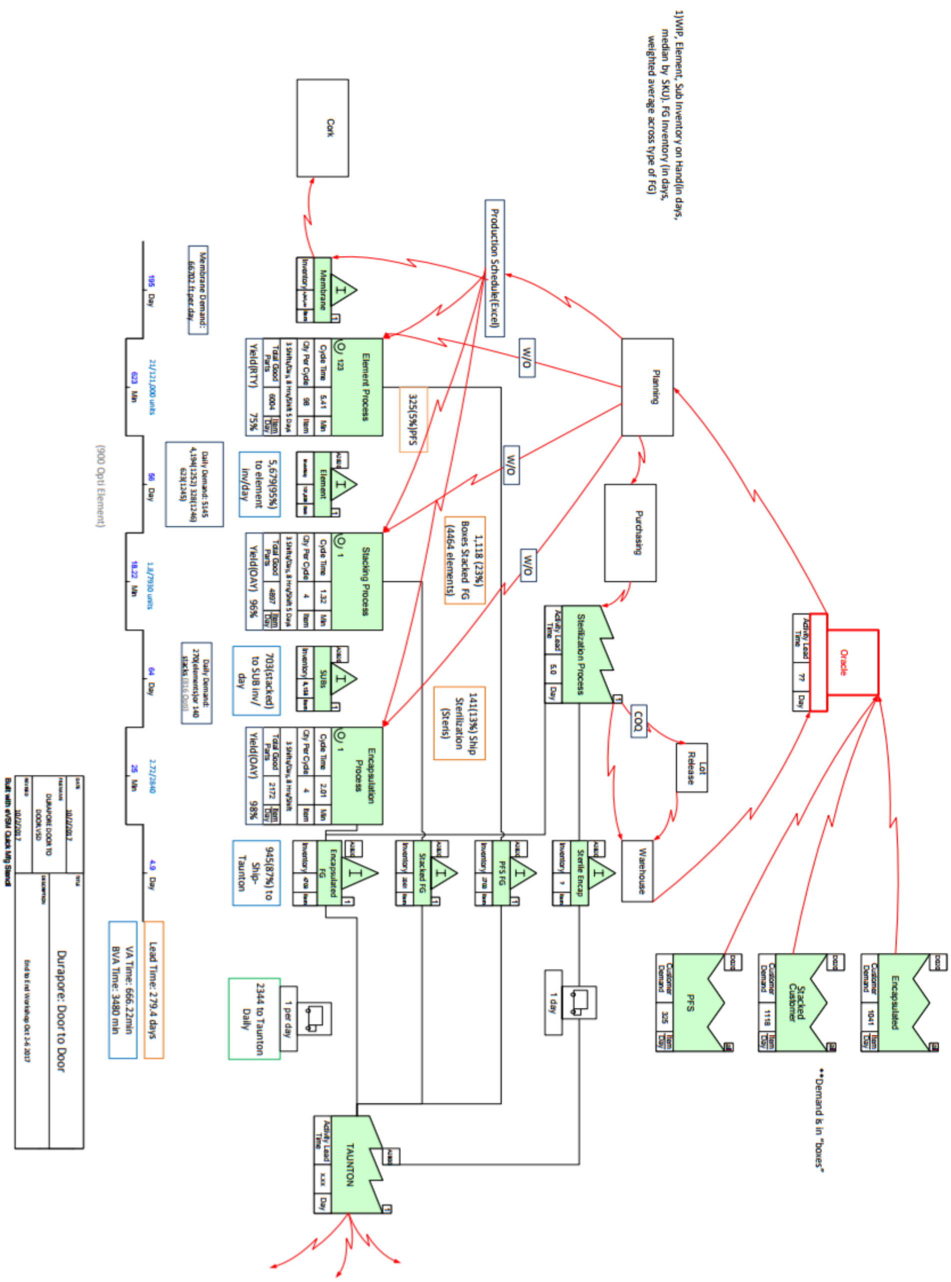
1) Define pull signals and communication across the plant
2) Develop a model for calculating the number of signals based upon lead time, yields, etc.
3) Develop safety stock models for stock locations within the processes
4) Evaluate improvement in Front and Back end planning systems
5) Provide a quantitative impact assessment to customer service levels, inventory, and lead times
6) Develop an implementation plan

Appendix 2: Lean Manufacturing Tools

Practice	Description	Tools	Benefits
Cellular Manufacturing	A cell consists of equipment and workstations. These are arranged to maintain a smooth flow of materials in the process of production. It also has qualified and trained operators to work at each cell.	1. One-piece flow: Each product moves in the line one unit at a time without sudden interruption at a pace determined by customer demand. 2. Extending production mix: When customers demand a high variety of products, flexibility is important. This can be achieved through grouping similar products into families that are processed on the same equipment and in the same sequence.	1. Product families result in less time required for changeover between products and encourage production in small lots. 2. Inventory (most frequently WIP) reduction 3. Reduced transport and material handling 4. Lead time reductions 5. Identification of bottlenecks 6. Improved productivity
Continuous Improvement	Kaizen is a Japanese word meaning continuous endeavor for perfection. It has become a best practice for a proactive environment and good management.	5S: Is the first modular step towards serious waste reduction. ● Sort: deals with removing items not being used on a regular basis. ● Straighten: assures having the right tools at the right area. ● Sweep: allows for a clean, neat ready to use for next ship station. ● Standardize: deals high standard norms and procedures. ● Systemize: trains people to follow the rules	1. Allows companies to reveal potential strengths and capabilities that were not evident before. 2. Potential to increase profitability

Just-in-Time	Attempts to eliminate all sources of waste in manufacturing by producing the right parts, at the right place, at the right time.	1. Pull system: Customer demand sends the first signal of production and the product gets pulled from the assembly. Each process pulls the needed parts from the preceding process further upstream. 2. Kanbans: Used to manage shipments of parts from station to station. It is an information system that is used to control the number of parts to be produced in each station.	1. Raw material, subassemblies and finished product inventory are kept at a minimum reducing holding costs. 2. Every product is produced at a pace no higher than that of the subsequent process' requirements 3. Quality problems can be detected early in the chain. 4. Storage space is reduced 5. Preventing excess production can make hidden problems evident.
Standardization of Work	It ensures that every job is organized and carried out in the most effective manner following the same processing steps all the time.	1. Takt time: refers to how often a product should be produced in a product family based on the actual customer demand.	1. Line balancing is achieved. 2. Unwarranted WIP is minimized 3. Non-value activities are reduced.
Zero Defects	Makes sure all products are fault free through continuous improvement of manufacturing process. It also aims to catch defects at an early stage.	1. Poka-yoke: autonomous defect control system that is put on a machine that inspects all parts to make sure there are zero defects.	1. Observes the defective parts of the source, detects the cause of the defect and avoids moving the defective part to the next station.

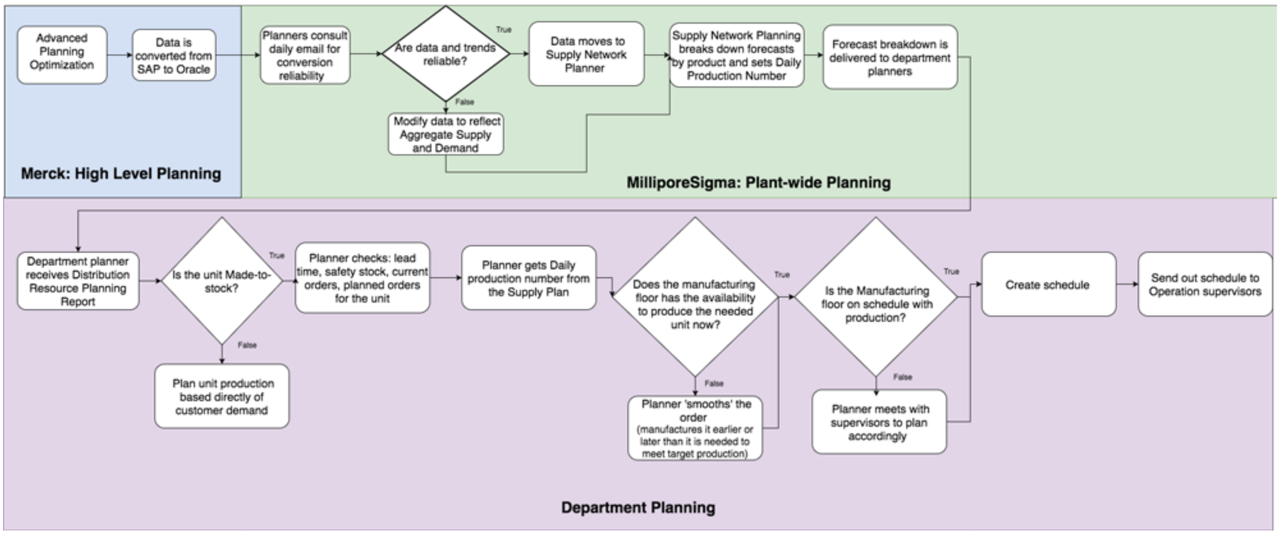
Appendix 3: Current State Value Stream Map



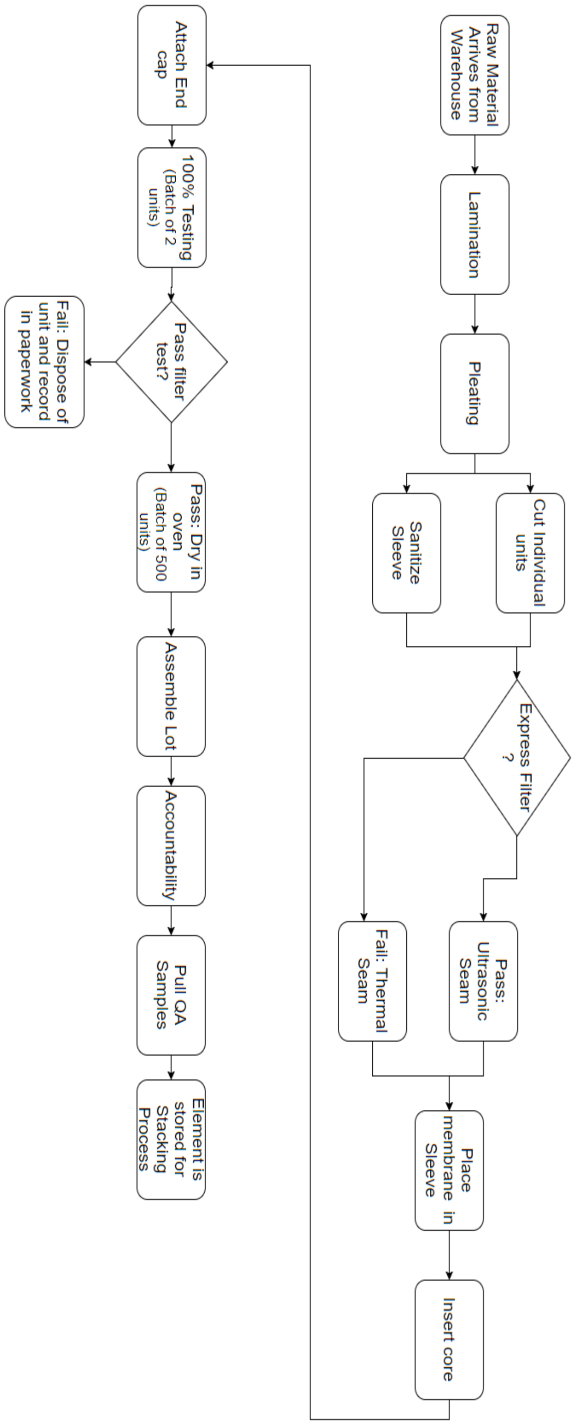
Appendix 4: Sorted Made-to-Stock CVGL Product Table

Component Item Number	Component Item Description	Item Number	Item Description	Inventory Item Status Code	GPH Code	WRKCNTR CATEGORY	CATEGORY
110605XCVGL	CVGL 0.22um 10" ELEMENT	41553X1	10" GL CODE 0 CART SUB	STOCK	MAD005SCC000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	41553X2	20" GL CODE 0 CART SUB	STOCK	MAD005SCC000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	41553X3	30" GL CODE 0 CART SUB	STOCK	MAD005SCC000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	CVGL01TP3	DURA TP .22U PHIL CD 0 10" 3PK	STOCK	MAD002PJA000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	CVGL02TP3	DURA TP .22U PHIL CD 0 20" 3PK	STOCK	MAD002PJA000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	CVGL03TP3	DURA TP .22U PHIL CD 0 30" 3PK	STOCK	MAD002PJA000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	CVGL51TP3	DURA TP .22U PHIL CD 5 10" 3PK	STOCK	MAD002PJA000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	CVGL52TP3	DURA TP .22U PHIL CD 5 20" 3PK	STOCK	MAD002PJA000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	CVGL71TP3	DURA TP .22UM PHIL CD 7 10" 3PK	STOCK	MAD002PJA000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	CVGL72TP3	DURA TP .22U PHIL CD 7 20" 3PK	STOCK	MAD002PJA000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	CVGL73TP3	DURA TP .22UM PHIL CD 7 30" 3PK	STOCK	MAD002PJA000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	FCPV020S2	Hydrophillic 0.22um PVDF 20in, Code 0	STOCK	MAD008AAB000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	FCPV030S2	Hydrophillic 0.22um PVDF 30in, Code 0	STOCK	MAD008AAB000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	FCPV730S2	Hydrophillic 0.22um PVDF 30in, Code 7	STOCK	MAD008AAB000	J1252	Durapore
110605XCVGL	CVGL 0.22um 10" ELEMENT	MSP000812	DURAPORE CVGL71TP BOX OF 48.	STOCK	MAD002PJA000	J1252	Durapore
110605XCVGLG	CVGLG 0.22um 10" Gamma Element	110648X1	CVGL 10" Code 0 .22um Gamma Subassembly	STOCK	MAD005SCC000	J1252	Durapore
110605XCVGLG	CVGLG 0.22um 10" Gamma Element	110648X2	CVGL 20" Code 0 .22um Gamma Subassembly	STOCK	MAD005SCC000	J1252	Durapore
110605XCVGLG	CVGLG 0.22um 10" Gamma Element	110648X3	CVGL 30" Code 0 .22um Gamma Subassembly	STOCK	MAD005SCC000	J1252	Durapore

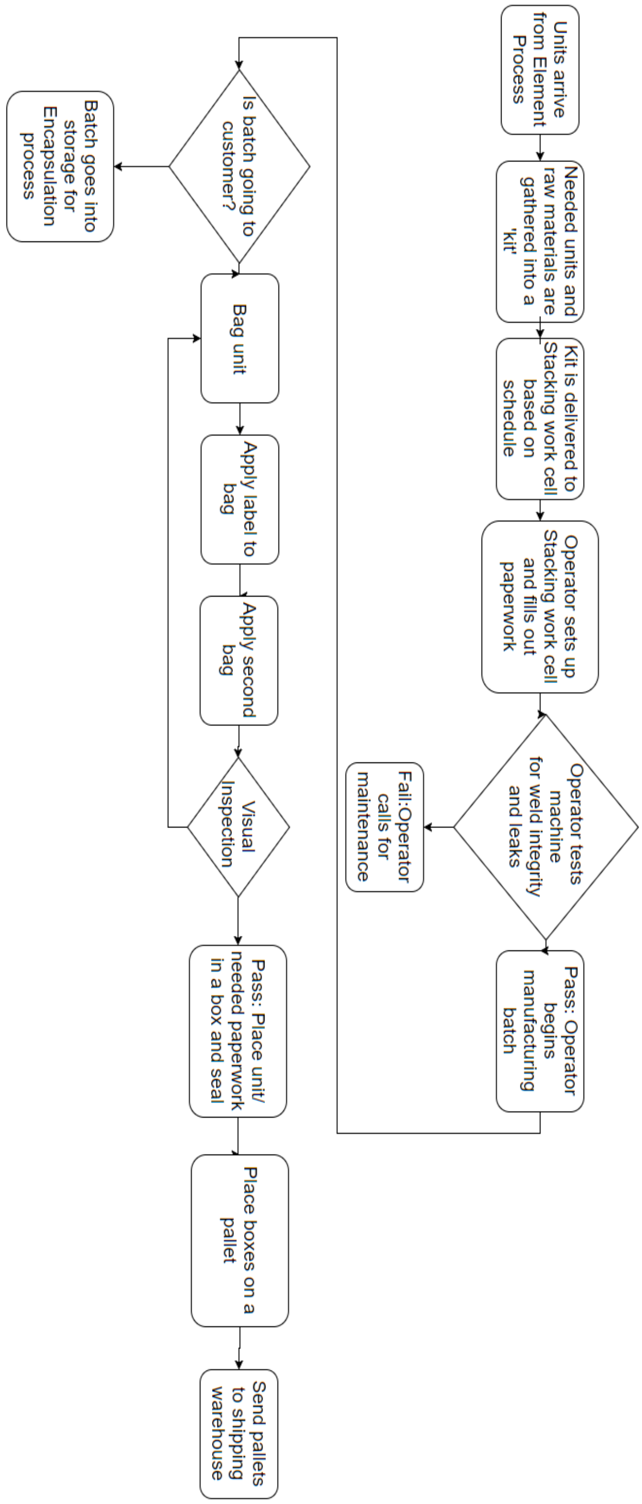
Appendix 5: High Level Planning Flow Diagram



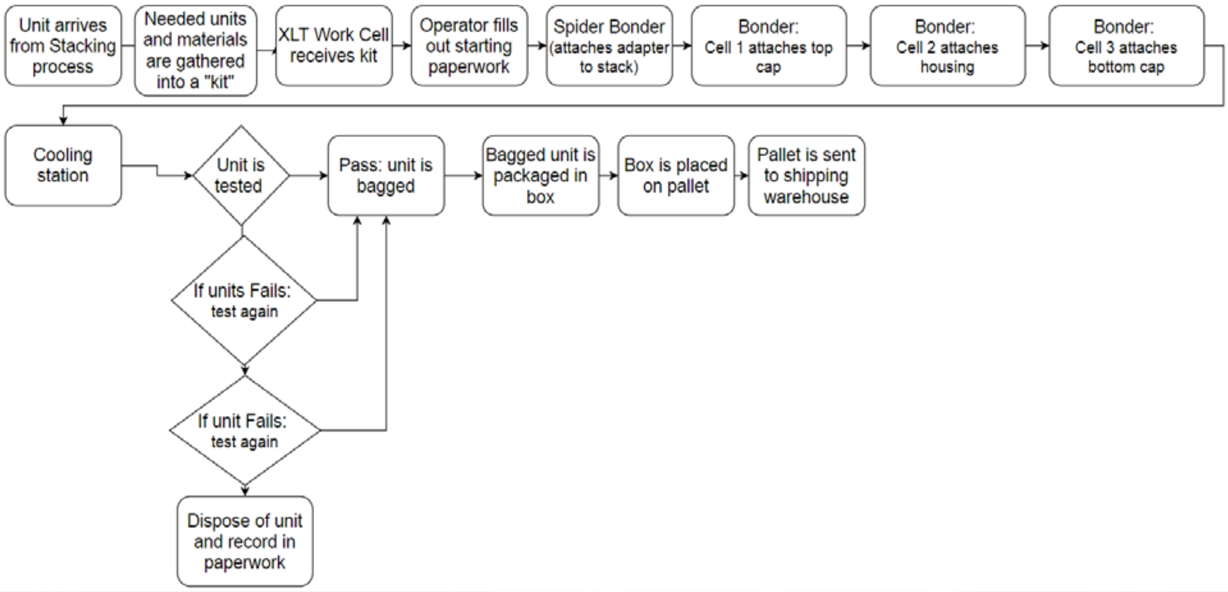
Appendix 6: Element Department Flow Diagram



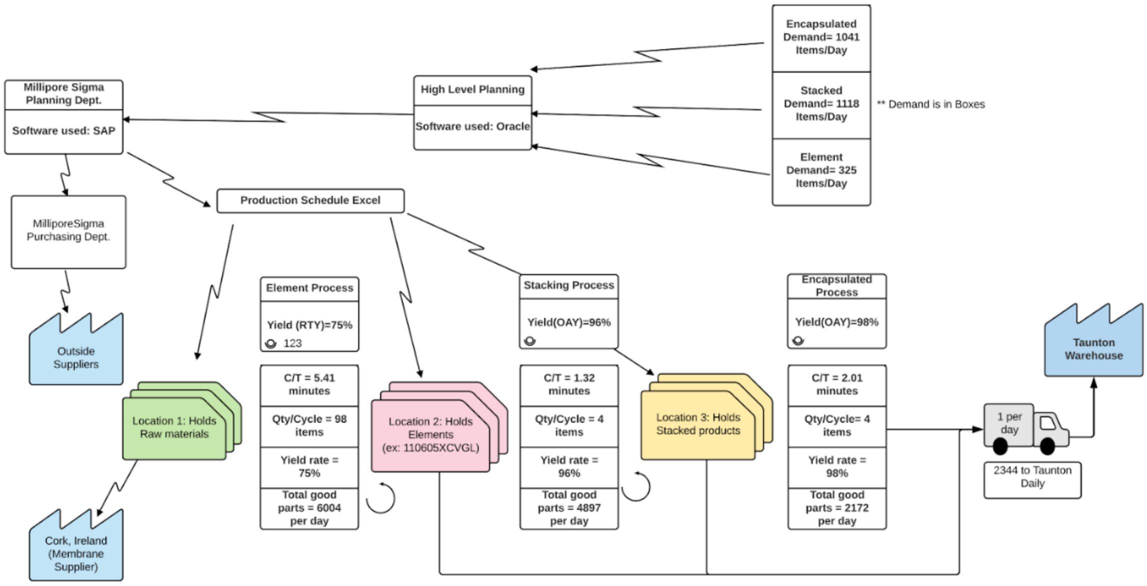
Appendix 7: Stacking Department Flow Diagram



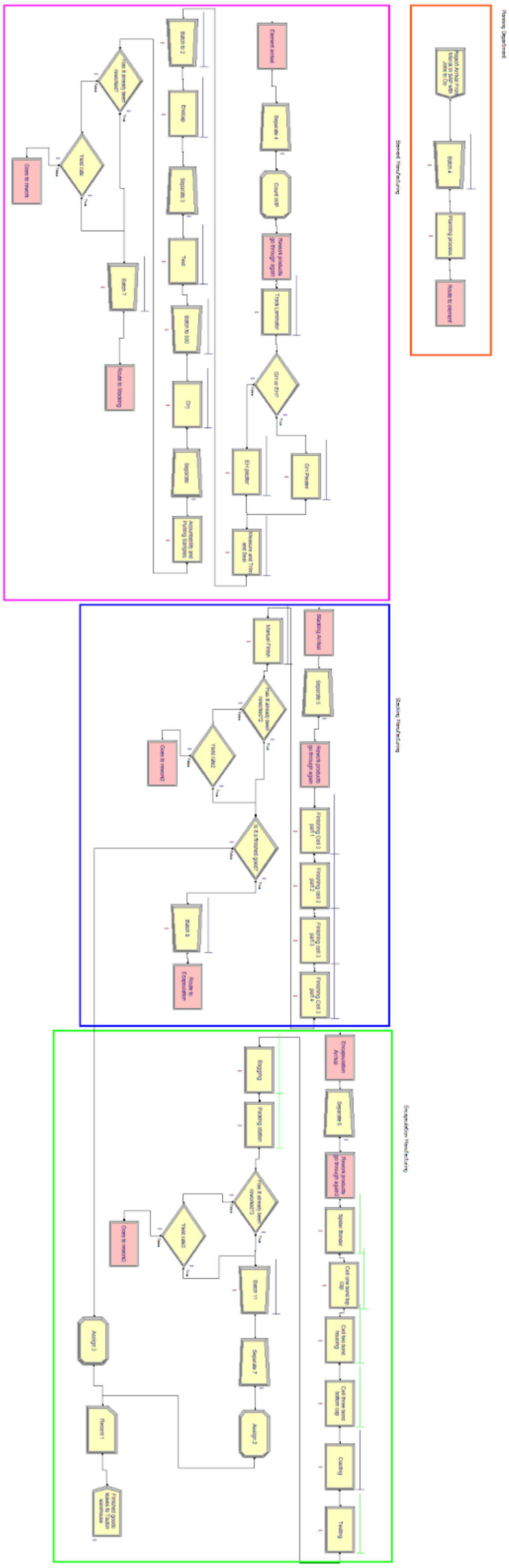
Appendix 8: Encapsulated Department Flow Diagram



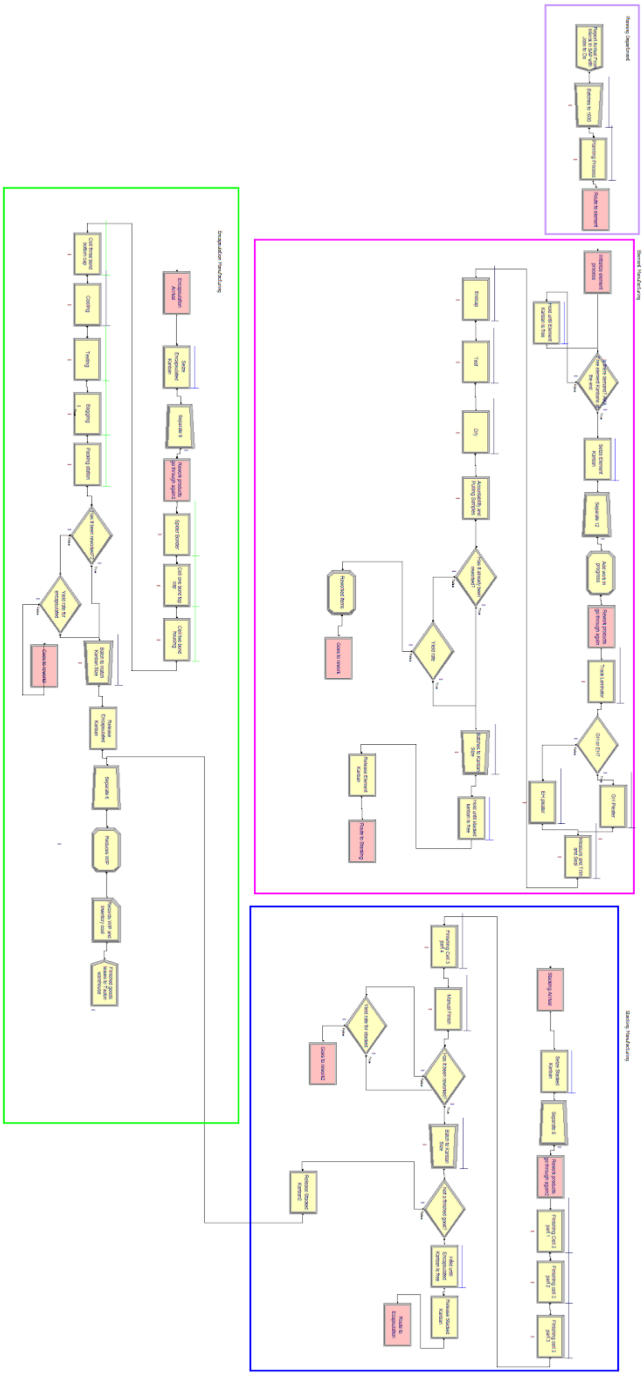
Appendix 9: Future State Value Stream Map



Appendix 10: Current State Simulation



Appendix 11: Future State Simulation



Appendix 12: Road Map