Production System Improvement:

Floor Area Reduction and Inventory Optimization

By

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B.Eng. Mechanical Engineering
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ABSTRACT

This thesis shows improvements of a medical device production system. The demand at the Medical Device Manufacturing Company (MDMC[1]) is low for the occlusion system product and there is a need to introduce other production lines on the floor. MDMC gave the challenge to the MIT team to improve the production area utilization rate and inventory management for the occlusion system product. This thesis shows the Six Sigma approach and methodology the MIT team used to reduce the occlusion system's floor area. Detailed approaches selected by the team in area reduction include supermarket decentralization, consolidation of equipment, removal of non-production items and change in bench configuration to reduce excess space. The floor reduction plan recommended reduces the production area from 1528 ft^2 to 1052 ft^2.

The thesis also covers the inventory management analysis and optimization that improves the operation efficiency and reduce inventory cost of this production line. Information regarding the other improvements including manpower allocation, cycle time analysis and visual management can be found in other team members' individual theses [1] [2] [3].

Key Words: Lean Manufacturing, Floor Area Reduction, Inventory Optimization, System Efficiency

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[1] Company name and product names are disguised for confidentiality. The company is referred to as Medical Device Manufacturing Company (MDMC)

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Chapter 1

Introduction

Manufacturing processes for disposable medical devices are moving towards fully automated processes. However, some disposable medical devices with relative high complexity are still manually assembled which is labor intensive and costly. The Medical Device Manufacturing Company is producing several different types of medical devices and some involve in house part manufacturing while others involve only assembly and testing operations.

Although a large portion of cost of goods sold is the raw material cost and part manufacturing cost, assembly and testing costs are also significant to the profit margin especially in a relative high labor cost country. MDMC is developing its own lean manufacturing team to carry out projects focusing on reducing such cost while maintaining or improving production system efficiency.

This thesis covers the project the MIT team performed at MDMC and focuses on two aspects: Floor area reduction and inventory optimization of a specific production line at MDMC.

1.1 The MIT-MDMC Project

Massachusetts Institute of Technology (MIT) Mechanical Engineering Department contains a program called the Masters of Engineering in Manufacturing. The program has a comprehensive curriculum covering Process and Assembly Physics, Factory and Supply Chain Systems, Product Design, and Business Fundamentals and Operational Excellence. Starting in the second semester of this program, MIT pairs teams of three or four students with local companies to work on a real world manufacturing project. Students spend one day per week in the spring semester for onsite or remote work and full time in the same summer term.

This thesis is a result of the work the MIT team performed at MDMC for the Masters of Engineering degree.

1.2 Company and Product Background

MDMC is a global leader in medical technology. MDMC has sales operations in over 100 countries. MDMC's product line includes a wide range of disease states

The MDMC manufacturing facility that is cooperating with MIT is the preferred partner for braided, extruded and therapy delivery products. This MDMC campus has two buildings of a total area of 104,000 square feet. 44,000 square feet of that space is a clean room manufacturing area. This MDMC site manufactures many different types of catheters. Other related manufactured products include occlusion systems and other accessories. The MDMC site has revenues of around $300 million with a volume of products of almost 6 million per year.

1.2.1 Occlusion System

This project focused on the production line of the occlusion system.

Emboli are the debris dislodged by catheter products in the arterial system. Embolic protection catheters are used to prevent emboli from moving down the bloodstream. The occlusion system is an occlusion type protection system. Occlusion blocks the artery beyond the target site and prevents emboli from passing by. A separate catheter is used to aspirate the debris from the artery. Occlusion system is used for both heart and brain applications.

There are three main components to the occlusion system product, the catheter, the syringe, and the accessory. The occlusion system catheter consists of many different materials and even subassemblies. It is the most complex assembly in this product.

The syringe and the accessory are mainly made of injection molded parts, and require different manufacturing operations. The different components, the occlusion system catheter, the syringe, and the accessory are produced on dedicated manufacturing lines.

All of the manufacturing processes performed onsite are manual and require a high degree of operator interface and skill. The line measures and tests the product's performance as well as manufacturing the product. Most of the processes require table top machinery and fixtures. There is only one shift operating on this line. The production associates on this line range from 4 to about 9 depending on volume demanded. The current floor space used by this manufacturing line is around 1500 square feet. The daily demand fluctuated between 20 to 55 units during the team's time at MDMC. Compared with other production lines, the occlusion system line is of low volume and with high demand fluctuations. The majority of the occlusion system Kits are sold in Japanese market.

1.2.2 Medical Device Regulations

Regulations are of significant importance to have a comprehensive understanding of this product. Occlusion system is a Federal Drug and Administration (FDA) Device Class II regulated product. MDMC would be required to resubmit a premarket notification if significant changes or modifications are made that could extend to the safety or effectiveness of the device. The FDA outlines that these changes or modifications requiring another submission "could relate to the design, material, chemical composition source, manufacturing process, or intended use." [4]

1.3 Floor Area Reduction & Inventory Optimization

This thesis is following two parallel lines in each chapter: floor area reduction and Inventory optimization. To meet the goal of lean manufacturing, the floor space taken by the production lines will be reduced to minimize footprint and maximize area utilization efficiency. The inventory management of the production lines will also be optimized to increase system operational efficiency and to save space at the same time.

1.3.1 Team Common Part: Floor Area Reduction

The expected outcome of this project is to provide a system efficiency improvement package and implement the changes to the production line. The improvement package consists of five aspects: Floor area reduction, inventory optimization, cycle time analysis, manpower analysis and visual management improvement. The whole team worked collaboratively with company employees on the common part of reducing the production line space while the other improvements are provided individually by each team member.

This thesis will be focusing on the common improvement of floor area reduction and the individual improvement of inventory analysis. For details of other improvements please refer to the same project theses by Zhuling Chen (Visual Management improvement), Abdulaziz Asaad AlEisa (manpower analysis), and Jennifer Jeanne Peterson (cycle time analysis).

1.3.2 Individual Part: Inventory optimization

While the entire team worked on the area reduction plan, to provide a final suggested layout and implement this layout, each team member has an individual concentration.

Abdulaziz AlEisa studied the current manpower and cross training status as well as the lead time for each subassembly. This section covers a comprehensive analysis of the new layout effects on the manpower requirement as well as future suggestions to increase the efficiency and flexibility of the production line.

Zhuling Chen analyzed MDMC's current system of visual management and provided revamped visual management system to track key performance indicators to reflect real-time production performance on the floor. The system is expected to facilitate communication between managers and the production associates.

Jennifer Peterson analyzed the cycle time of the current layout. She analyzed the process map using metrics like space, batch sizes, and line balancing to explain the resulting cycle time of the certain process. She presented a new process map to show the tradeoffs in cycle time. Suggestions are provided showing possible ways to improve cycle time and the productivity of the space used.

Tianying Yang analyzed the strategy of decentralizing the supermarket and provided a decentralization plan. The plan provides a replenishment schedule that minimizes parts inventory on the floor where appropriate. To implement the new replenishment strategy, bins on the supermarket are combined with bins containing same parts on the benches. New color coated Kanban cards are designed with bench number indicated. Different replenishment rules for different subassemblies are unified, for example, Kanban replaced the network ordering on the computer for sheath assembly line. Other detailed problems will be considered during supermarket decentralization like feasible ways to store large size containers underneath work benches.

1.4 Overview

Chapter 2 identifies the problem and objectives of this project. Chapter 3 provides literature information involved in this project and relates the literature used to the project. Chapter 4 presents the methodology used to tackle this problem: from first studying and analyzing the existing production line to defining the approaches to reduce the floor space and optimize the inventory. Chapter 5 presents the results of the improvements, the detailed analysis of proposed floor layout and how inventory is optimized. Chapter 6 includes summary of recommendations and possible future work.

Chapter 2

Problem Statement

2.1 Problem Identification and Objective

The primary objective of this project is to improve the system efficiency in Occlusion system assembly line. One key objective is to reduce Occlusion system footprint by one third of the original area before the end of August 2012 as the space is too large for the volumes produced. The space is needed to introduce new production lines for future product. Other goals of this study include optimizing cycle time, manpower allocation among different subassemblies, material replenishment strategy, and implementation of effective visual management.

This project allows the team to adjust the following:

- Tooling and fixtures.
- Process flow and working benches for the occlusion system's catheter, accessory, syringe, and sheath.

There are certain design elements that are out of scope for this project; in particular, those outside the floor layout include the following:

- The coating and packaging areas.
- This product is a FDA regulated medical device. The team must avoid new regulatory filings caused by changes to the design specifications or materials.

2.2 Current Layout

The Occlusion system manufacturing area is fitted in along one other production line and the wall in the manufacturing area of MDMC's Building A. The measured area of 1528 square feet includes the necessary aisle space for the production benches. The total production line length is approximately 170 feet, where line length only includes the length of the production benches.

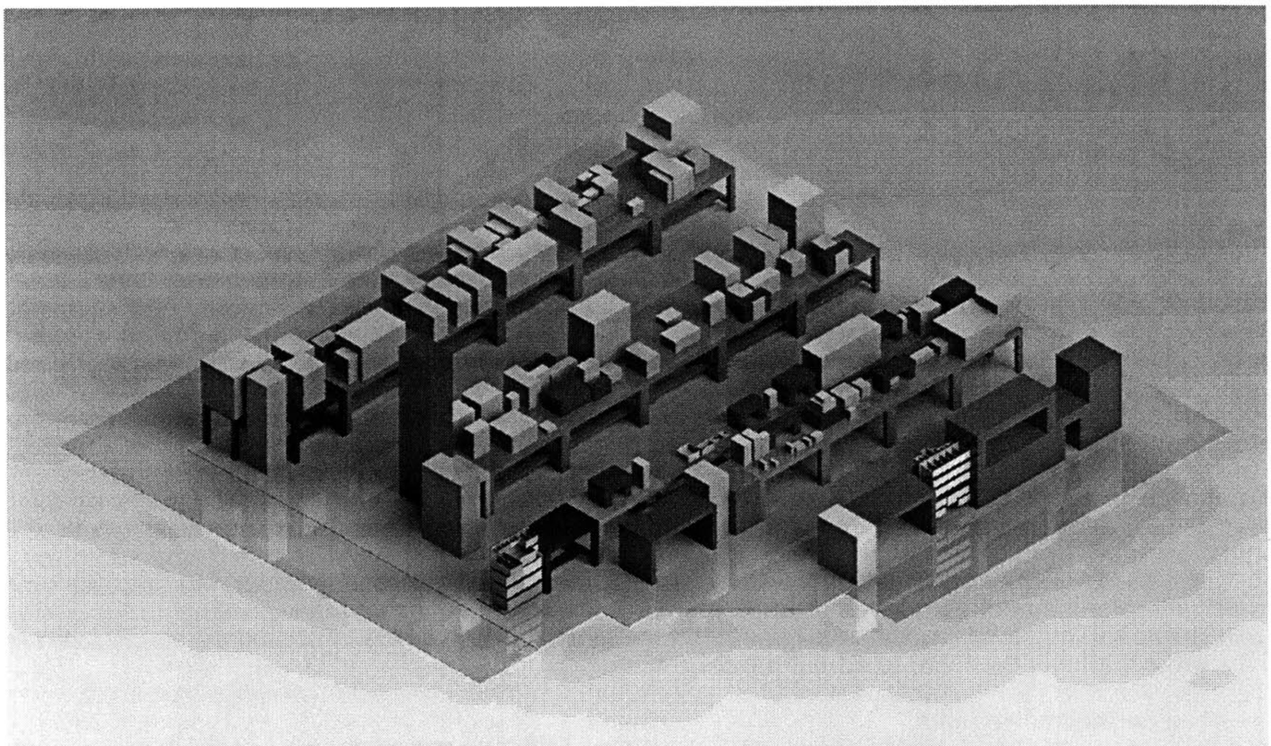


Figure 2.1: Occlusion system's Current Layout

As shown in Figure 2.1, the production area's current layout consists of seven rows of production benches, computer desks, cabinets, and shelves. Most of the equipment is placed on the production benches. However, some equipment is placed to the side, above or below. Each production bench is dedicated to particular assembly procedures.

The catheter line consists of approximately 22 production benches, distributed along four rows of benches. The total line length used for the catheter is 120 feet. The equipment used for the catheter assembly include many microscopes, laser micrometers, ultraviolet light source machine and ultrasonic cleaning machine. The current operations require space for the long catheter to lay flat on the production benches. Depending on the volume required that day, there are four to six production associates working on this line.

The Accessory line has six production benches all in one row, with a line length of 29 feet. The equipment used for the Accessory assembly includes an ultraviolet curing machine, presses, fume hoods, and screwdrivers. The Accessory line has usually one to two production associates working on this line.

The syringe line has three production benches all in one row, with a line length of 20 feet. Equipment used for this line include fume hoods, presses, and screwdrivers. The syringe line has usually one to two production associates working on this line.

The Sheath has two production benches for a total line length of 12 feet. Much of the equipment is specialized for just this assembly, including a microscope and hotboxes. There is usually one production associate working on this subassembly.

The supermarket areas include an area along the fifth and seventh row. The total length of the supermarket areas is 6 feet.

Other area include computer desks, cabinets, chemical storage areas, along with other miscellaneous items. The total length of these other areas is 30 feet and is split up among all of the rows. All these area are shown individually in Figure 2.3 to demonstrate the protion of each part in the whole floor layout.

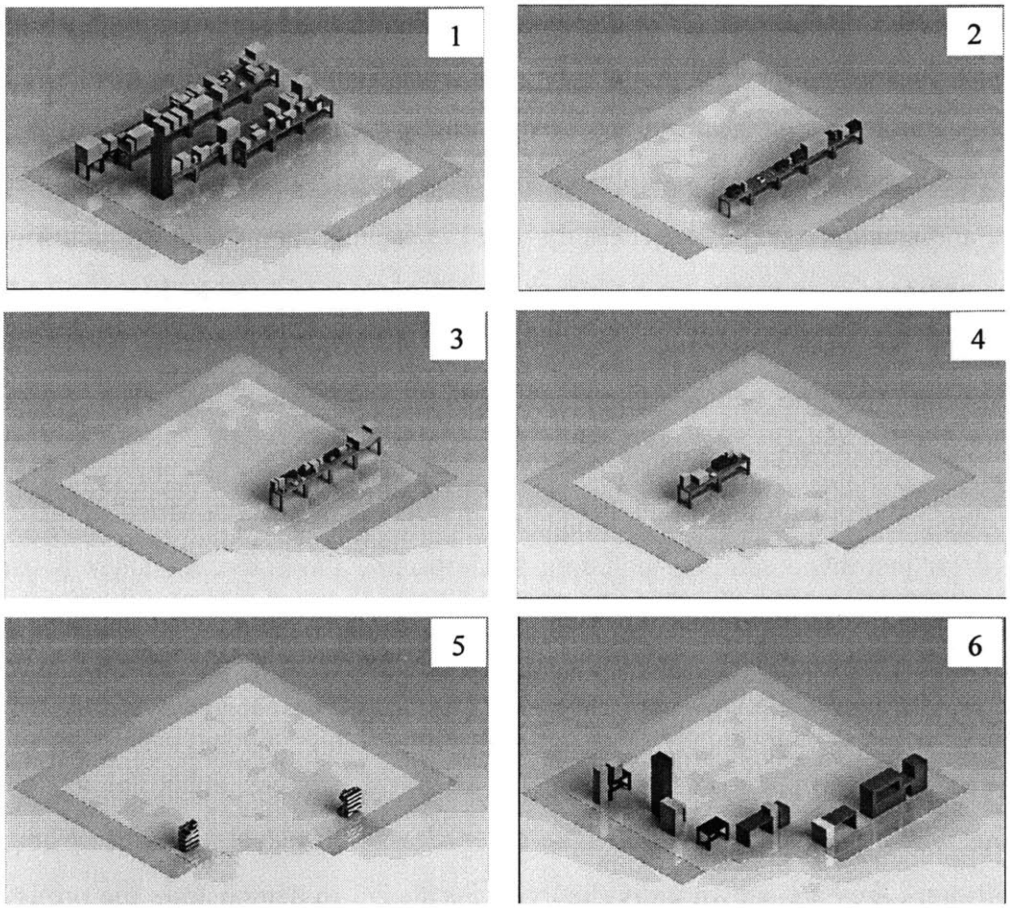


Figure 2.2: Production Benches of the Catheter (1), Production Benches of the Accessory (2), Production Benches of the Syringe (3), Production Benches of the Sheath (4), Supermarket Areas (5), Other Non-Production Areas (6).

These results are summarized in Table 2.1. Longer subassembly lines means higher possibility of consolidation and more potention space for reduction. Since subassembly lines cannot be combined in this project, Table 2.1 offers a quantitive view of where opportunity lies.

Table 2.1: Current Occlusion system's Layout Data

	Rows Used	Benches	Total Line Area (sq feet)	Production Associates
Catheter	4	22	270	4-6
Accessory	1	6	73	1-2
Syringe	1	4	50	1-2
Sheath	1	2	30	1
Supermarkets	NA	NA	15	NA
Other Areas	NA	NA	124	NA
Total	7	34	562	7-10

2.3 Evaluation Criteria from MDMC perspective

The main evaluation criterion is the amount of space reduced in square footage. However the freed up space must be usable to MDMC, meaning that the space should be large enough to place production benches. In addition the space saved should be preferably contiguous and within easy access to the space from the main passage. MDMC would prefer a solution that is as low cost as possible that requires as few purchases as possible. Purhcases for the new layout should justify their benefit in terms of space saved.

When designing the new layout, all aspects related to the production system are considered to maintain reasonable efficiency of the line. The following four improvements ae weighted equally: Cycle time should not be compromised in order to fulfill the maximum demand of the product. Parts replenishment should be as efficient as before to prevent shortages and place inventories at the most accessible locations. The new layout should also provide flexiblity in manpower allocation on the line for varying demands. In addition, visual management should be in place to monitor production performance and enhance information flow on the floor.

2.4 Inventory Optimization

The inventory management of this production line was set up in different time periods in the past and is not adopting the same system for the subassembly lines. A lot of opportunities exist for improvement like reducing safety stock in the supermarket, adopting the same system to improve system efficiency and improve replenishment strategy to serve the main objective to save production space. The inventory management consists of finished product inventory and supply inventory. Finished products are stored onsite and ready for packaging. Supply inventory includes the part supply supermarket and other consumables like wipes. Due to the scope of this project, only supply inventory optimization is studied in this thesis.

Finished Product Inventory

This production line produces all the needed subassemblies. Currently these finished subassemblies are stored on the floor and shipped to the packaging area in another room of the manufacturing facility where they will be packaged into one kit. Since there are two mechanisms triggering production at the same time and there are some conflicts between these two mechanisms, there is potential to use only one mechanism to reduce finished subassembly inventory. The first mechanism is to use production schedule. The line lead of the subassembly lines will receive a projected production schedule for the coming week which will be used to guide production. So occasionally when this line produces more than the capacity of the packaging line, subassembly inventory will stack up. At the same time, the packaging line is using the Kanban system, which means they will signal the subassembly lines to produce when the packaging line is about to run out of required subassemblies. This mechanism prevents production line from storing finished subassembly products. If only the Kanban system is used, finished product inventory will be eliminated at the price of sacrificing buffering ability to fluctuations.

Supply Inventory

Similar to the finished good inventory, supply inventory also has different replenishment mechanisms. For example, catheter and syringe lines use the Kanban replenishment mechanism. The Sheath line uses network computer ordering linked to the company warehouse. The accessory line uses similar mechanism to the Kanban system but use log book instead of company standard Kanban cards. Standardizing the mechanism will reduce supply inventory.

Other potentials for improvements include: package size, bin size and bin storage. Details will be discussed in the methodology section.

Chapter 3

Literature Review

In order to understand the methodologies used in the manufacturing field, the team researched methodologies such as lean manufacturing, Six Sigma, and lean sigma. The team also looked at examples of past area reduction projects to gain insight on how to reduce this area. For my individual section I researched the manufacturing supermarket and Kanban system.

3.1 Area Reduction

3.1.1 Lean manufacturing

Lean manufacturing is a manufacturing philosophy that focuses on continuous improvement and reduction of waste. The system encourages maintaining a smooth flow throughout the manufacturing process. It reduces the amount of inventory in the system, thus shortening the cycle time and reducing the cost of work-in-progress parts. The concept was derived from the Toyota Production System in late 20th century. It was discussed by John Krafcik [5]; Krafcik introduced two new terms buffered and lean production systems. Krafcik mentions how the production systems of most Western producers after World War II were buffered against almost any problem with high component and finished goods inventory levels. The core elements of lean manufacturing consist of inventory management, set-up reduction for flexible capacity, cells design, Andon, Kaizen, and Poke-Yoke [6].

Inventory management aims at reducing inventory at warehouse and work-in-progress inventory. Process flow is designed to have the same cycle time. Working parts are passed to the next stage at the same time the next process is available. Line balancing is applied in order to equalize the takt time for each process. The system is tuned to be reliable, embedded with mechanisms to self-correct, so that the process flow is smooth without disruption by defects. In order to reduce inventory levels, a pull system is created with Kanban to indicate the status of the system. As a result, timely replenishment can be achieved and lower inventory levels are required on the floor. Shorter set-up time reduces the downtime during changeovers, making it less costly in terms of time to manufacture another product, thus increasing line flexibility.

Cell design features sequential operations. Machines and tools are grouped according to the family of parts being produced in the line. One part is produced while moving around the cell. In doing so, one-piece flow is achieved, improving material flow and significantly reducing cumulative lead time.

Andon refers to a system that notifies all personnel, such as management, maintenance and engineers, responsible for a quality or process issue on the floor. A signaling system can be activated either by manually pressing a button by a worker or automatically by a monitoring system. It assigns workers the responsibility to stop production in the occurrence of a defect and calls for attention. As a result, problems can be resolved once they occur [7].

Kaizen is a daily process, focusing on continuous improvement of business. The current operation is reviewed on a daily basis to eliminate waste and improve process reliability. It requires constant engagement of workers as well as management in the organization. The culture of continuous improvements leads to significant overall productivity improvement.

Poke-Yoke is a mistake prevention system to avoid defects and human errors, thus improving quality yield. Workers are responsible for the machine they use and parts being produced. Together with Andon, part quality is checked at every cell, problems are made visible to whole working team immediately.

Womack in *Lean Thinking* stresses the importance of creating value for the customer [8]. All these tools and methods outlined above, including flexible capacity, cells design, Andon, Kaizen, and Poke-Yoke can help to create value. The objectives of the lean enterprise are to correctly specify value for the customer across the firm, to identify all the actions involved in the product, and to remove any actions which do not create value. In addition in the continuous process of Lean Manufacturing, once you fix a process, fix it again.

3.1.2 Six Sigma

The Six Sigma approach name comes from that in a normal curve, six standard deviations or sigmas, from the mean on each side constitute 99.99966% of the sample. There would only be 3.4 defects per one million. Motorola's Bill Smith introduced the Six Sigma method in 1986 [9]. According to Motorola University, Six Sigma is a metric, methodology, and a management system. Six Sigma started as manufacturing effort that was then applied to other business processes to reduce defects. It became even more popular when General Electric Corporation adopted Six Sigma in the mid-1990s as part of leadership development. The Six Sigma approach also introduced and supported the idea that improved quality pulls down the overall cost.

The focuses of Six Sigma are to understand and manage customer requirements, align business process to achieve those requirements, utilize data analysis to minimize variation, and drive rapid and sustainable improvement to these business processes [10]. The data analysis involves statistical techniques, such as control charts and statistical process control. The second generation of Six Sigma has taken into consideration situations where Six Sigma does not apply as well, particularly human intensive processes such as marketing and human resources [11].

3.1.3 DMAIC

DMAIC was developed as a problem-solving procedure in the Six Sigma approach that guides a project by evaluating root causes of problems and implementing best practices to improve those processes. DMAIC consists of five steps, namely define, measure, analyze, improve and control. The five steps are conducted in sequence and can be used as milestones for project management. The define phase is to identify valid improvement opportunity, clarify critical customer requirements and establish a project charter to define project goals. The measure phase is to determine what variables to measure, collect data in a planned manner. In the analysis phase, collected data is analyzed to determine process capability, throughput and cycle time. Hypotheses are made to verify root causes for variation. After hypotheses are established, the improve phase generates potential solutions based on data analysis and actions are taken to evaluate the validity of solutions. The final solution is reached in this phase and approval for implementation takes place. In the control phase, attentions are paid to monitor and control critical outputs. Continuous improvements are made to avoid mistakes in the system [12].

3.1.4 Lean Sigma

Lean Six Sigma is an approach focused on improving product quality, reducing variations in production and reducing cost at the same time [13]. It is a combination of two process-improving techniques, Six Sigma and Lean Manufacturing as described above. The outcome of these two combined contradicts the prevailing view at that time this method was introduced that quality is at the expense of extra production cost.

A lot of studies have been done on Lean Six Sigma applications in private sectors. Maytag Corporation designed a new production line using the concepts of Lean Six Sigma in 1999. The production lines space was reduced to one third of the original lines. Maytag also cut production cost by 55% [14].

3.1.5 Concerns about Lean Six Sigma Approaches

In 2000, the board of 3M selected James McNerney as the new CEO. McNerney was trained in the Six Sigma practices taught by Jack Welch at General Electric. McNerney implemented these Six Sigma practices cutting costs and improving productivity, however at the risk of new projects. 3M had been successful because of its innovation and creativity. The statistical analysis did not apply well when in the research and development process there are few facts and the nature of the problem is undefined. If unchecked the culture of Six Sigma can stifle creativity because the motivations of each culture are very different. Six Sigma stresses analysis, while innovation stresses creativity and new projects [15].

The lasting impact of lean manufacturing and Six Sigma projects can be questioned as well. Almost 60% of companies to implement one of these programs fail to yield the desired results. The program's success can be declared too soon and the managerial emphasis is lost leading to increased discouragement. The gains made using these methods can then slip away. Ways to continue the successful use of these projects can include keeping the involvement of improvement experts, lining up incentives with improvement initiatives, small teams and small time frames for the projects, and finally maintaining direct involvement from the executives [16].

3.1.6 Lean Sigma at MDMC

MDMC began focusing on their use of lean sigma techniques in 2006. From MDMC's training manual it says "In Lean Sigma there is a saying: blame the process, not the people." The Lean Sigma method combines the waste removal, process efficiency thinking of Lean, with the variation reduction and quality improvement techniques of Six Sigma.

The method that MDMC uses usually follows the pattern of first balancing the flow of the processes using lean manufacturing methods and then using Six Sigma practices to reduce the variation of the process [17].

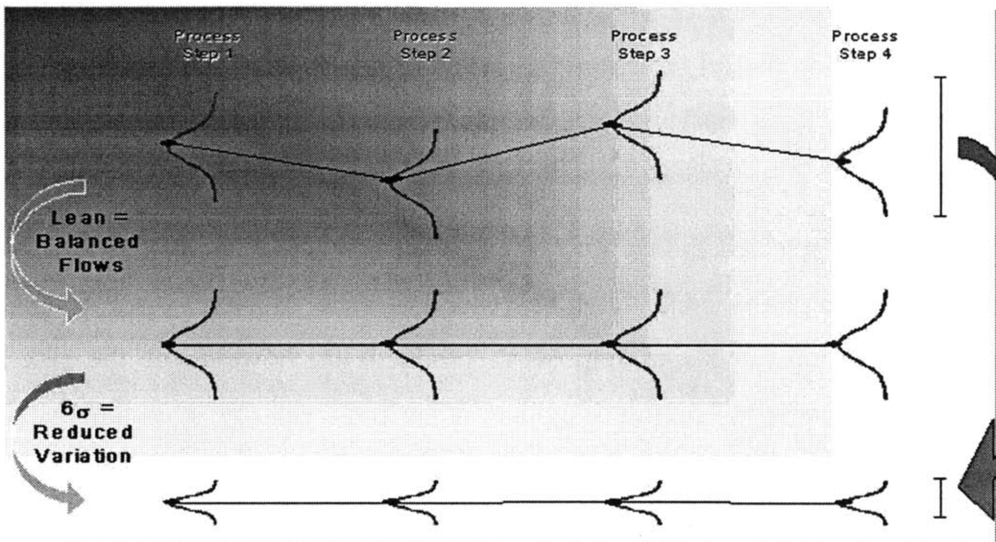


Figure 3.1: Lean Six Sigma Methodology at MDMC

An example of a successful Lean Sigma project at MDMC is the catheter product. In 2007 MDMC implemented these practices on the Cather. In the period between 2007 and 2010 the average yield increased from 89% to 94%. The productivity increased which reduced labor costs per unit from $5.04 to $3.07. There was a decrease in lead time as well from 5.4 days to 3.7 days. The sales increased as well as a decrease in customer complaints [18]. MDMC uses many Lean and Six Sigma tools, including the DMAIC methodology. Other Lean and Six Sigma tools include 6S, VSM, MSA, Kaizen, Kanban, C&E Matrix, A3, Standard Work, and DOE.

3.2 Manufacturing Supermarket and Kanban system

As mentioned in the lean manufacturing session, manufacturing supermarket and Kanban system are two important concepts in reducing inventory of the Toyota Production System (TPS). Taiichi Ohno originally developed the manufacturing supermarket concept from American supermarkets. Customers take away products on the shelf and suppliers are notified to initiate replenishment process. A supermarket is a storage place located near production area. Production operators on the downstream pull parts from the supermarket and warehouse suppliers replenish low storage level parts in the supermarket.

Kanban cards are used to deliver empty signals from supermarket to suppliers. When the storage level of a certain type of parts in the supermarket is low, for example less than one day's supply, the supply Kanban card is delivered to the warehouse to initiate replenishment. It is part of visual communication. Kanban is a scheduling tool with all required information to start production.

Chapter 4

Methodology

This part elaborates the methodology used in this project to analyze and improve the manufacturing system. This part is divided into two sections: methodology for floor area reduction and methodology for inventory optimization.

From the beginning of the project, the team adopted the DMAIC problem-solving procedure in the Six Sigma approach, which is shown in figure 4.1:

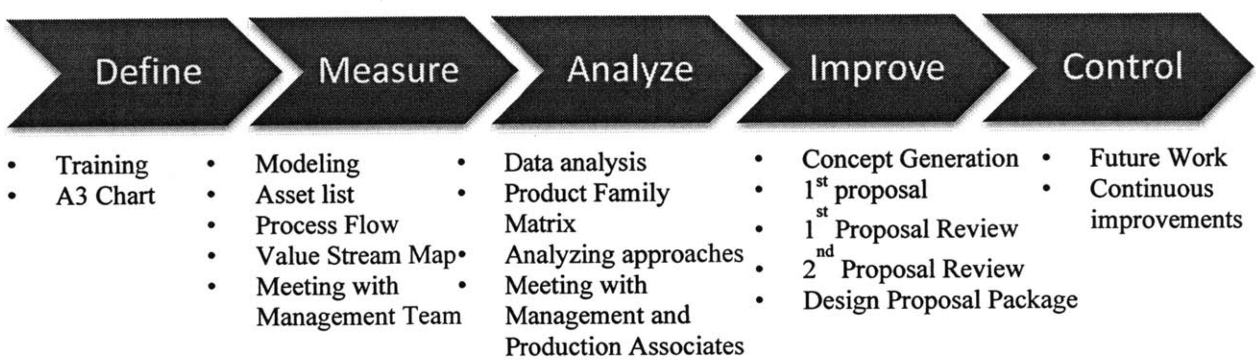


Figure 4.1: DMAIC problem solving procedure for MDMC project

The Define phase includes defining the scope and goals of the project. The Measure phase involves studying the current production line, collecting data, modeling and learning the underlying value stream map of the production line. The Analyze phase includes data analysis and proposing basic approaches based on the potential opportunities in the define phase and the result of the data analysis. The Improve phase includes proposing new layout, improving the layout and providing the whole improvement package. The Control phase includes continuous improvement in the future.

The Measure and analyze stages will be discussed in this methodology section. Contents of improve stage will be elaborated in the results and discussion section. Control phase will be discussed in the future work section.

4.1 Floor Area Reduction

The procedures adopted on area reduction in the methodology part consist of three steps: Studying the current layout, analyzing data and model and summarizing potential approaches. In the first step, benches on the floor are numbered and the whole floor is modeled using a 3D modeling software. The value stream map is then studied. Product family matrix is used to analyze collected data for potential consolidation of equipment. Summarized approaches are the results of analyzing collected data and model.

4.1.1 Bench numbering system

The original numbering of the system was following the manufacturing process sequence and had different prefixes for occlusion system Accessory and Syringe. For example, the first workbench in the occlusion system line following the process was named W1; the third workbench in Accessory line was named A3. Detailed numbering is shown in the 2D CAD drawing Figure 4.2:

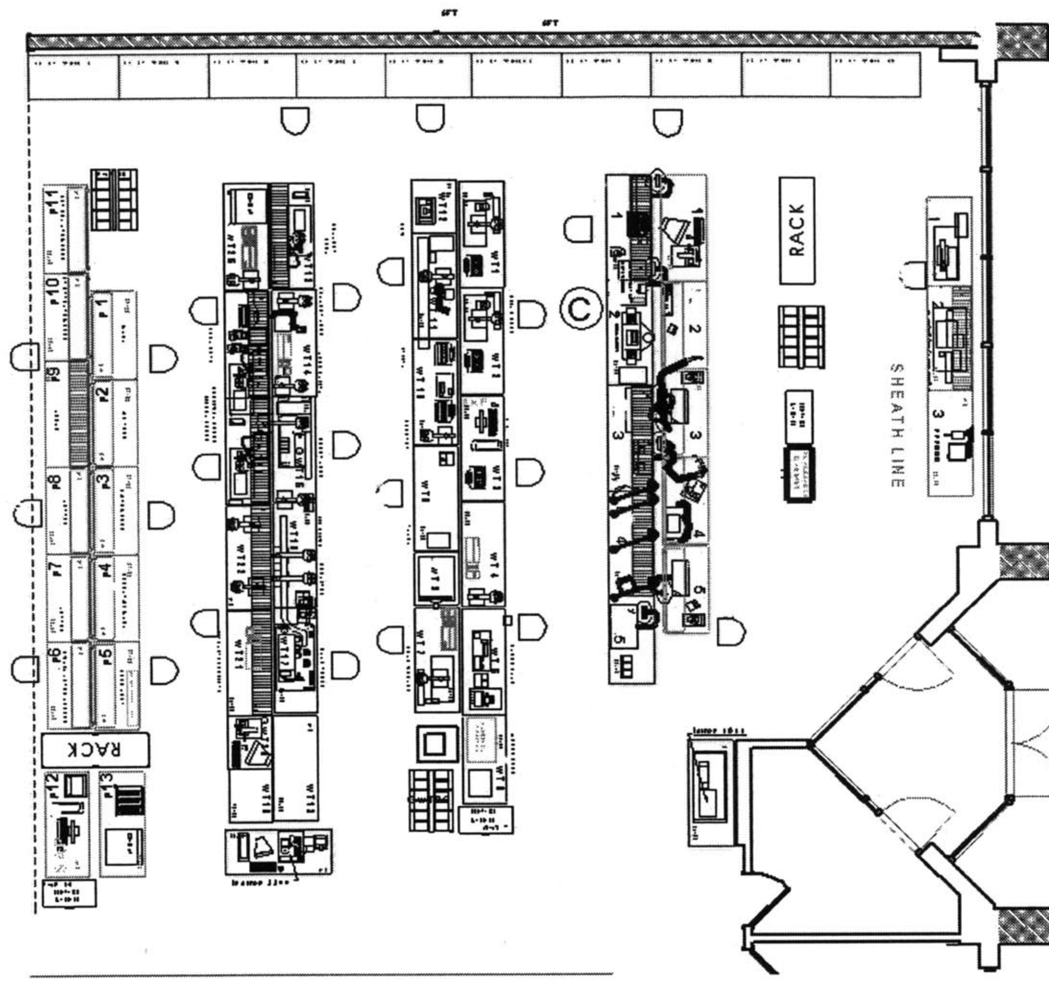


Figure 4.2: Original Bench Numbering

A new numbering system has been used throughout the project which guides the moving process better. According to the row number and the sequence in the row, each bench is numbered with two digits. Rows are numbered from left to right. Benches are numbered from top to bottom. For example, the third bench in the fourth row is numbered 4.3. The Instron machine table besides the office is named separately as 8.1. The renumbered layout is attached in Figure 4.3:

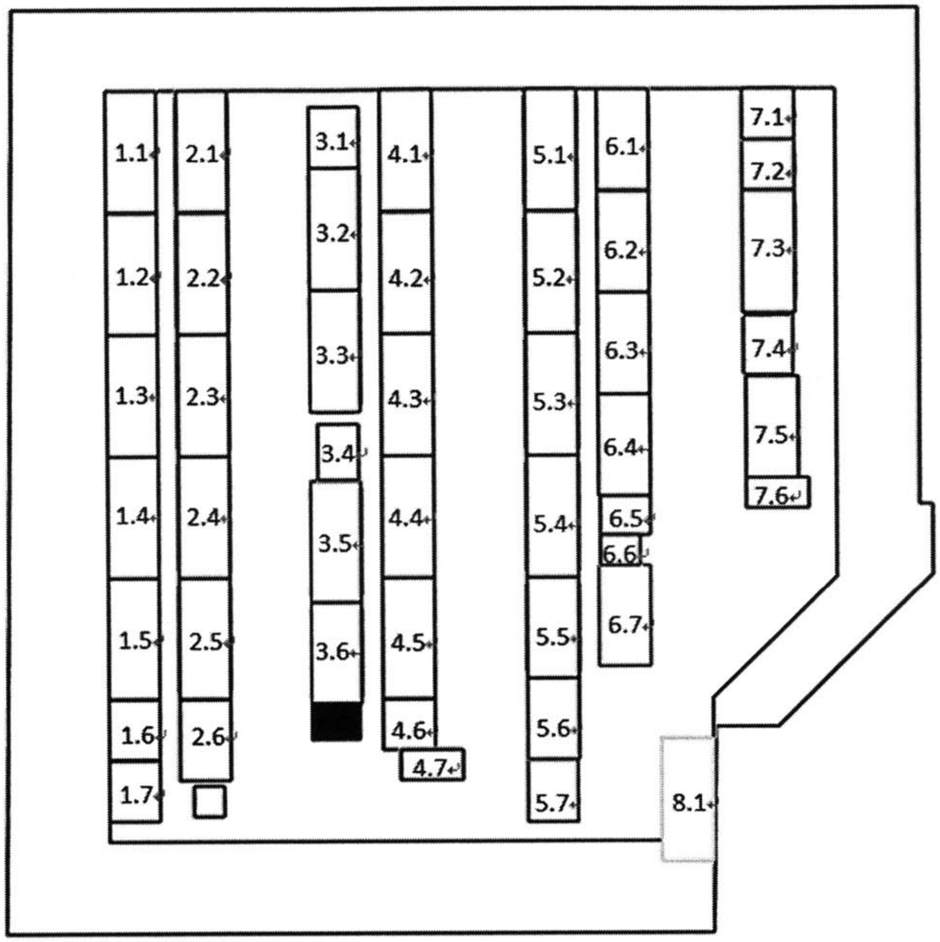


Figure 4.3: 2D Sketch of the Occlusion system Floor with the Current Bench Labeling

4.1.2 Modeling

The Computer aided design software, Solid Works, was used to develop the three dimensional models for the current floor layout to facilitate concept generation and proposal validation. The model is of real scale and was used to rearrange benches for new layout designs and validating proposed designs.

The Solid Works includes four categories of parts: production floor area with boundary walls, workbenches, nonproduction parts and apparatus. MDMC owns one blue print of the floor layout which is shown in the first figure in the Bench numbering system section. The file is a two dimensional CAD drawing which is modified and included in the final package.

Production floor area with boundary walls: the pink highlighted area represents outer aisle of the production area. The darker floor represents where benches are located.

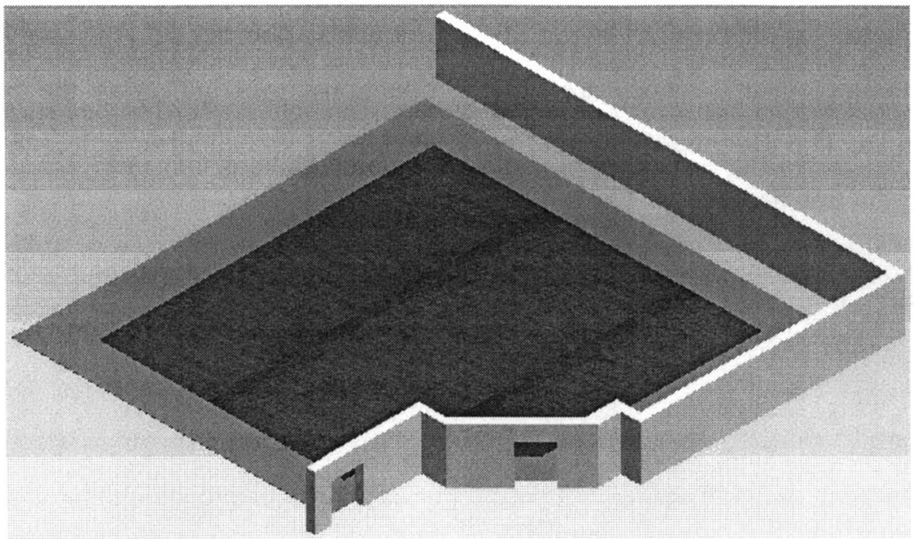


Figure 4.4: Floor area and boundary Model

Workbenches: the workbenches used are Phoenix Workbenches. Original models are not available from the company so benches are constructed from measurement. Five different sizes of workbenches are used in this production area: 2.5, 3, 4, 5 and 6 foot benches. A six foot long bench model is shown in Figure 4.5 as an example.

Apparatus: To simplify the modeling process, most apparatus are modeled as a block with length, width and height. Apparatus include force test equipment, leakage test equipment, microscope, laser micrometer, ultrasonic cleaner and so on. All the apparatus are located on the corresponding workbench as they appear on the floor. A fume hood model is shown in Figure 4.5 as an example.

Nonproduction parts: computer desks, file cabinets and supermarkets belong to nonproduction parts. A model of one supermarket is shown in Figure 4.5 as an example.

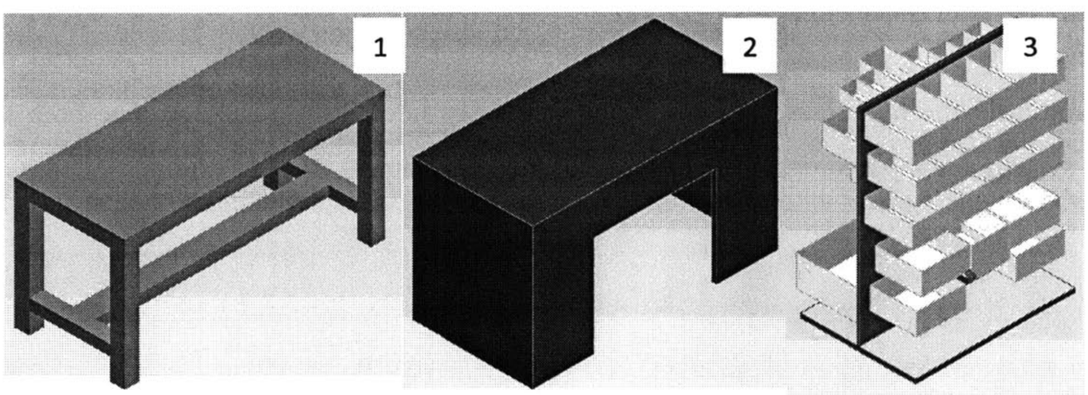


Figure 4.5: Table Model - 6 ft. Long (1), Fume Hood Model (2), Supermarket Model (3)

The whole picture of the original layout of the production floor model is shown in the following figure. The empty cyan benches are other productions lines indicating the boundary of the production area. The distances between lines are carefully measured to reflect the real operation space for production associates.

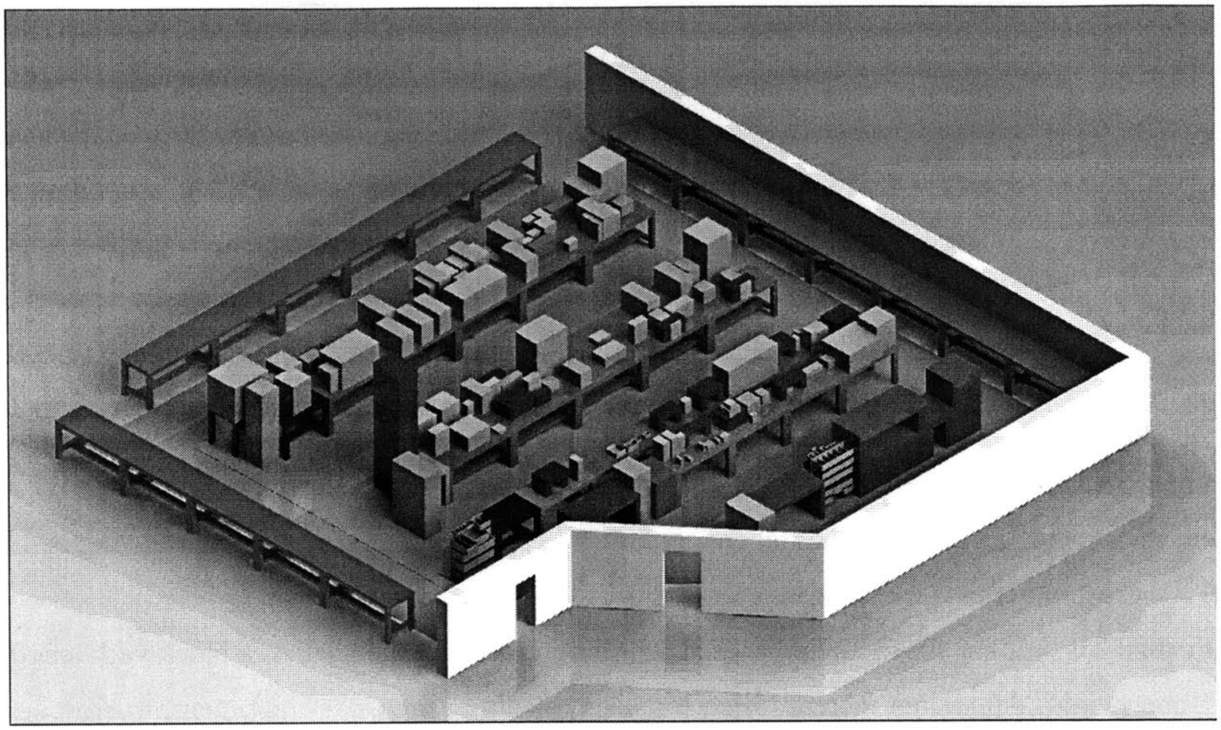


Figure 4.6: Original Layout Model

4.1.3 Process map

Through interviews with the warehouse personnel, the line lead, line manager, and planners; the team developed the part of the process map that showed how information and material flowed before and after the manufacturing process. The supply side and the demand side both have a Kanban system and a planning system that triggers replenishment or production.

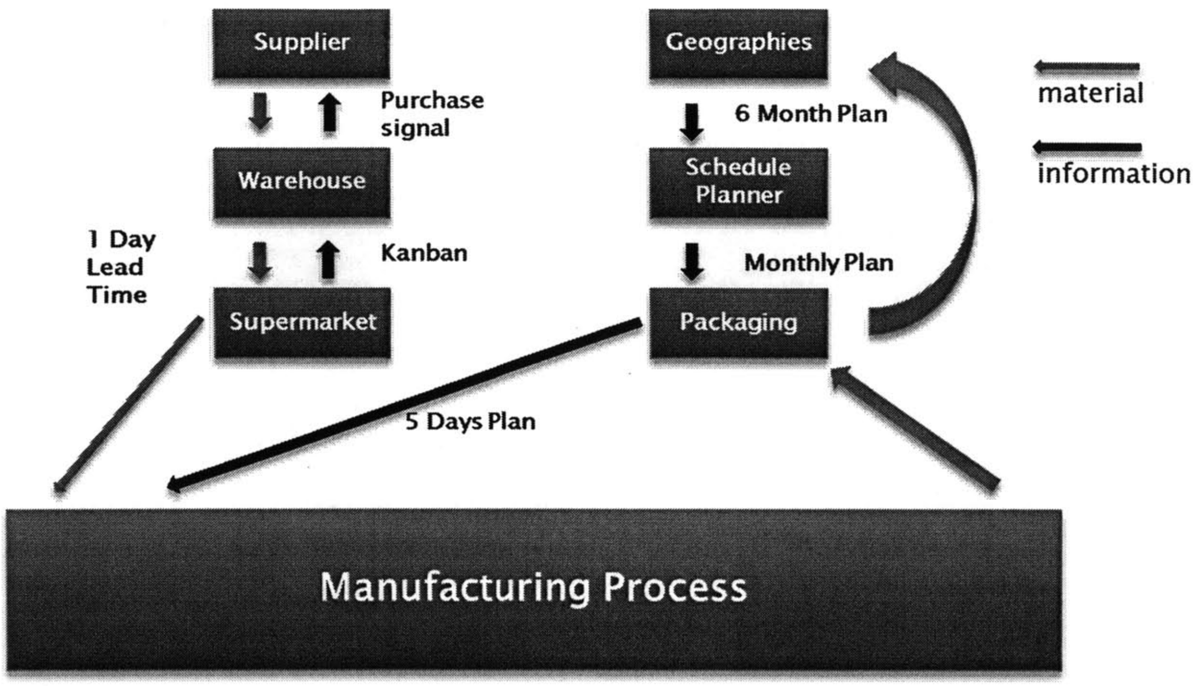


Figure 4.7: Supply and Demand Flow

During the time period of January 23, 2012 to January 26, 2012, measurements were made on the floor of individual processes. The demand was approximately 50 pieces a day during that time. A batch size averages 50 pieces for the catheter, 100 pieces for the sheath and 65 pieces for the Accessory and Syringe. The measurements taken were both for the operations on one piece as well as the operations on the entire batch size. Some fixtures are able to perform the same function on multiple pieces at the same time, so both measurements were necessary. The individual and collective data also created a check in the system as to ensure that the individual measurements of the processes were reasonable.

4.1.4 Product Family Matrix

Product family matrix is used to analyze potentials for equipment consolidation. Some common equipment is used for different subassembly lines and through product family matrix potentials for consolidation can be evaluated for different equipment.

There are over 22 different machines used to manufacture the parts of Occlusion system. This is not counting the completely unique machines manufactured just for this line. The common parts are in the table 4.1. The matrix allowed the team to look for opportunities to reduce the floor space by combining equipment for two uses or by looking at lines that use similar equipment.

Syringe and Accessory use similar machines. Occlusion system has 20 microscopes and 11 fume hoods that could be shared.

Table 4.1: Occlusion system's Product Family Matrix

	Microscope	Air Blower	Ultra Sonic Cleaner	Laser Micrometer	Hotbox	UV Light Source	Press	Fume Hood	Adhering	Screwdriver
Syringe	-	-	-	-	-	1	3	2	2	1
Accessary	-	2	1	-	-	1	2	5	2	3
Sheath	-	-	-	-	1	1	-	1	1	-
Catheter	20	2	3	5	3	2	-	3	-	-
Total	20	4	4	5	4	5	5	11	5	4

4.1.5 Asset list with dimensions

In order to build an accurate floor model and to ensure smooth movement process, the whole equipment and tools at the Occlusion system floor were surveyed and the asset list table is in the appendix. It includes physical dimensions, current location, voltage, and air requirement for each asset.

4.1.6 Principles

Following the evaluation criteria from MDMC's perspective and the team's understanding and analyzing of the current floor layout, four principles were selected to reduce the floor layout. The four principles are: identification and removal of non-production areas from production floor, centralized supermarket compared to point of use inventory, consolidation of equipment and new bench configuration. A thorough discussion among all principles provides various methods of reducing floor area. Linking some of the principles generates different design proposals.

4.1.6.1 Removing non-production items

Non-production items are taking valuable production space in the clean room. Items like file cabinets can be removed to save space for production. "Clean room" is the term used at MDMC to call the area that all production activities are conducted. The space is limited in the two buildings. Therefore, it is important to increase the utilization of production area.

Identification of non-production items

Production items are those that are directly associated with production and assembly, including working benches at which production associates performed each operation, spaces that production equipment are placed. Those spaces are used to add value to the product itself. Non-production items are items that are not directly involved in value adding but are still located on the floor.

One observation on the floor is that there are a number of objects that are not directly related to production activity. Those include cabinets, refrigerators for chemical storage, computer desk and so on.

Cabinets are very common on the floor. Some cabinets store files for maintenance technicians, production records while others store consumables and used as temporary storage space for work-in-progress parts. The cabinet use takes up considerable space on the floor and the majority of things stored are not facilitating production. Refrigerators are placed on the production line to store chemicals, such as glues, that require storage at low temperature. Glues are small items compared to the size of refrigerator and the consumption rate is low. Excessive refrigerators are noticed on the floor. Computer desks are placed on the floor for various purposes. Safety trainers are stationed on the floor using computers to track safety documents. Computers for technicians are placed on the floor as office space. Other computers are used for production associates to log production records. Although each computer serves a purpose on the floor, it is noticed that none of the computers are being used fully. In addition, it is verified by the management that it is not a requirement to keep those benches on the floor. We identified cabinet, refrigerator and computer workstation as non-production items.

Table 4.3 summarizes the number of production and non-production items on the floor. The number of production items including working benches and supermarket is 36 and the number of non-production items is 11. That is, non-production items consist of 25% of total objects on the floor. Therefore, sorting out and removing non-production items from the floor will increase the utilization of production space.

Table 4.2: Number of Production and Non-Production Items in Occlusion system's Floor

Type	Working Bench	Computer Desk	Cabinet	Chemical Storage	Supermarket	Total
Number of items	33	4	4	3	3	**47**

Removal plan

In order to remove non-production items from the production line, while not disrupting daily production activity, combining storage space, relocating non-production items to less valuable space and decentralizing redundant storage are considered.

There is one refrigerator on Occlusion system line which is merely used to store a small number of glues. After consulting the technician on the floor, we identified an opportunity to store those glues in another refrigerator on the floor which works under the same setting. By doing so, the refrigerator can be moved for other usage and space is saved. Another benefit goes to the maintenance side, as less equipment needs to be maintained therefore technicians could be freed up for other work.

Computer workstations can be relocated out of "clean room" as those people do not have to work on the floor. The production space should be only used by production associates to make products. Facilitating parties are to be stationed in office area or less valuable place.

Cabinets that are storing files or act as temporary inventory storage should be removed. Files that are not required to be on the floor should be stored in archive place. Those required ones should be stored in smaller cabinets and placed underneath working benches in order to save space. Big cabinets should be eliminated so that they are not used as temporary inventory storage.

4.1.6.2 Decentralizing inventory to point of use

Centralized supermarket

Currently two centralized supermarkets are on the floor for Occlusion system subassemblies. Bins are placed on a shelf with Kanban cards with part number and name. Production associates obtain parts from supermarket every morning. A warehouse associate collects Kanban cards of parts with low inventory level at the end of the day and delivers replenishment the next morning. The centralized supermarket makes it easy for inventory management. Because all inventory parts are located in one place, warehouse associate do not have to deliver parts to each working bench. On the other hand, centralized supermarket takes up a lot of space: part of row 5 and half of row 7 are used as supermarket. In addition, since parts are not at the place where they are used, production associates have to go to the supermarket to obtain one day's inventory and store them on the floor.

Point of use inventory

Opposed to centralized inventory, a point of use inventory strategy locates each inventory at the place it is used. For example, a jaw spring is part of Accessory. Therefore, it should be stored on the working bench assembling Accessory. There are two ways of placing inventory bins: on the shelf, attach to bin rail. Each working bench has a shelf for placing documents and bins. It is above equipment on the bench; hence, bins can be stored on the shelf without disrupting operations on the bench. However, the elevation of shelf could require a certain height to reach parts on top of it. Bin rail are long plastic strips that are fixed at the back of working benches. Bins are then screwed on bin rails. Bins are therefore more accessible compared to on the shelf in terms of height but they may interrupt operations because they are close to bench surface. A decentralized inventory system meets our project objective, as it takes no space on the floor to store inventory.

4.1.6.3 Consolidating equipment and shortening benches

The current layout of Occlusion system is filled with a lot of equipment due to the large number of operations required. One way of reducing floor space is to consolidate equipment and thus reducing number of working benches. For processes that require the same type of operations, one piece of equipment can fulfill all operations instead of having dedicated ones for each process. In order to understand the type of equipment used as well as their quantities on each line, a product family matrix was formed.

As shown in Table 4.1, various types of equipment are used on the line like optical microscope and mechanical screwdrivers. Microscopes are the most used equipment. There are 20 microscopes on the catheter line and a total of 11 fume hoods on the floor. The number of production associates on the occlusion system production line is around six to eight. Most of the microscopes are idle during production time. This suggests that there is excessive equipment on the floor which can be consolidated. However, before consolidating equipment, equipment has to be reviewed with great care to ensure it performs identical operation compared to the one being consolidated. Technical review and specification review are conducted by consulting the quality engineer and technician.

The set of equipment required by syringe and Accessory are observed to be similar. Both lines require UV Light, fume hood, press machine, adhering and screwdriver. All operations on syringe and Accessory lines are manual assembly and adhering parts. This similarity suggests that one set of the equipment can be utilized to perform both syringe and Accessory operations, although only one can be performed at one time at the expense of cycle time. However, this will eliminate one production completely and save considerable space for this project. One design based on this finding will be discussed in the next chapter.

4.1.6.4 Change bench configuration

Another principle is to explore alternative line configurations besides the current layout in order to have a better process flow and increase utilization of space.

As discussed in problem statement, the current layout consists of 7 lines of benches. Material flows along lines sequentially. This layout has a simple process flow but the aisle space between each line is significant. In common manufacturing practice, other layouts include job shop, U-cell and transfer lines. Each layout has its unique characteristic in manufacturing activities and also in terms of space utilization. We conducted brainstorming sessions to look for alternative configuration and discussed the trade-offs specifically in our project. A detailed discussion is in chapter 5.

4.1.7 Concept Generation

Brainstorming different layouts

Several brainstorming sessions were conducted to come up with different proposals for the production floor layout utilizing the principles and Solidworks model highlighted in the previous two sections. Those sessions were conducted internally (within MIT team members) and externally (including Occlusion system Management, quality group, technicians, and production associate from MDMC). Moreover, the sessions were conducted in the form of informal meetings, floor walkthroughs, or individual discussion.

New Layout Characteristics

Although the main goal of the project is to reduce the footprint of the Occlusion system production line by one third of the original area, there are other criteria that are significantly considered before selecting the most appropriate layout. Those criteria are:

1. **Saved Area:** The new layout should save as much area as possible.

2. **Area Utilization:** The new free area should be useful for MDMC in a way that it can be utilized for other purposes. In fact, there are no specific metrics to measure this factor; however, the area should have appropriate dimensions to fit new assembly line(s).

3. **Cost of Rearrangement:** The floor rearrangement should be done with minimum investment cost and with minimum interruption to the production process in the floor for different products.

4. **Ease of Rearrangement:** The rearrangement process should be done with minimum manpower and paper work requirements.

5. **Tools Maintenance Time:** The new layout should be designed to minimize the required time for maintenance of the equipment and tools.

6. **Production Capacity:** Despite the current low production demand, maximizing the production capacity is desired for the new layout to account for unexpected demand increase in the future.

7. **Safety:** The area reduction should not be on the expense of the safety on the production floor. Maintaining a minimum width of 4 ft. for the aisles between the working benches and 3ft for the aisles toward the emergency exit are vital requirement for any design proposal.

4.2 Inventory Optimization Analysis

As mentioned in chapter 2, the supply inventory was studied and analyzed. Three steps were taken to improve inventory management efficiency and save production space at the same time. Through studying the history of the two supermarkets, one important finding is that the subassembly lines' supermarkets were not built at the same time and there exists discrepancies of replenishment strategies between subassembly lines. The first step aims to standardize the replenishment strategy to simplify the replenishment process and improve system's efficiency. The second step aims to reduce supply inventory storage space by optimizing replenishment package size. The last step aims to decentralize the supply inventory in an efficient and convenient way that is least disruptive to the current production force.

4.2.1 Analysis of inventory replenishment strategy

All four subassembly lines have their supermarket on the floor. Catheter line's supply inventory occupies a whole supermarket cart while syringe and accessory lines' share one cart and one shelf. The sheath line is small so the supermarket is decentralized on the benches already. The replenishment methods for these four subassembly lines are listed in table 4.3:

Table 4.3: current subassembly lines part replenishment strategies

	Replenishment Method	Using Kanban cards	Person in charge
Catheter	Kanban system	Yes	Warehouse Associate
Sheath	Ordering through the intranet of the company	No	Production Associate
Syringe	Kanban system	Yes	Warehouse Associate
Accessory	Kanban system	No	Warehouse Associate

The new layout will adopt only one replenishment strategy for all four subassemblies. The three characters on the first row of table 4.3 have to be determined. Since the majority of the lines are using the Kanban system which has been proven efficient, the sheath replenishment method is suggested to the Kanban system. Thus Kanban cards will be needed for all the lines. Because of the decentralization of the supermarket to point of use, it will be more convenient for each production associate to be in charge of monitoring the inventory level on his or her bench. The unified replenishment strategy will improve the organization of parts supply and simplify the replenishment work on the system level.

4.2.2 Analysis of inventory

The package sizes of supplies are analyzed in this section to reduce unnecessary inventory on the production floor while keeping the same safety level of not running out of supply during production time.

The supermarket on the floor consists of two storage carts and one shelf of four layers. Bins are stored on the cart and large plastic containers are stored on the shelf (Figure 4.8). Replenishment packaging quantities are analyzed to reduce excess inventory onsite. Most replenishment is one package amount of supply.

Figure 4.8 Supermarket shelf (1), Supermarket cart (2)

Sizes of the containers are listed in table 4.4. Each bin contains only one type of part supply. Through observation, supply in the supermarket can be divided into three categories: consumables like blades and chemicals, small parts like springs and plastic buttons, large injection molded parts like syringes. Consumables come in compact packages and lasts for a long period. Small parts are stored in small bins and usually come in bags of hundreds pieces. Large parts are stored on the shelf and are space consuming. The following analysis will be focusing on large injection molded inventory which has the largest potential of space reduction.

Table 4.4: Part Container sizes

Category	Quantity	Width (in)	Length (in)	Height (in)	Kanban Card size
Bin 1	8	4	5	3	3"*2"
Bin 2	13	4	8	3	3"*2"
Bin 3	51	6	11	5	4"*2"
Bin 4	5	8	11	7	4"*2"
Bin 5	4	11	11	5	4"*2"
Bin 6	12	16	15	7	4"*2"
Bin 7	4	18	12	8	4"*2"
Bin 8	4	6	19	6	3"*2"
Plastic Box	9	22	16	12	4"*2"
Plastic Bag	2	22	16	12	4"*2"

The part refill package size mainly depends on factors of inspection frequency and production rate. Currently the warehouse associate inspects the supermarket once a day at the end of the production shift and refills the supply on the morning of the second day. Assume production rate is normally distributed with an average of μ and standard deviation of σ. With daily refill frequency, packaging size can be described by the following equation assuming one package per refill:

$$\text{Package size} = \mu + N * \sigma \quad (1)$$

The possibility of running out of part supply depends on N and can be found in table4.5:

Table 4.5: Possibility table

N=	Possibility of running out of supply
1	15.87%
2	2.78%
3	0.13%

Current production rate μ is around 30 pieces per day and the historical standard deviation is 10 pieces per day. Depending on safety factor N we can propose a new package quantity and reduce part inventory storage space.

4.2.3 Analysis of inventory reallocation

As discussed in 4.6.1.2, the containers on the two supermarket carts and the shelf will be decentralized to point of use. Before the movement, it is important to ensure there is enough space at point of use for these containers and also taking human use factors into consideration. This part of analysis utilizes observations on the floor and combines methods that already exist with new methods created for storage. Based on onsite observations, containers are commonly stored in three ways: underneath the workbench, on the bench (including hanging on the bin rail) and on the shelf.

To facilitate the decentralization, first step taken is to create a detailed list of container size, quantity and corresponding production bench of point of use. Second step taken is to fit each container into one of the three storage categories. Third step is to determine extra accessories needed for allocating the containers. Last step is to advertise the reallocation to production associates and gather feedbacks for improvement.

Chapter 5

Results and Discussion

Chapter 5 is divided into two main sections. Section 5.1 discusses the results of the occlusion system's floor reduction. While Section 5.2 present the results and discussion of the inventory optimization.

5.1 Occlusion system's Floor Reduction Results

Three different designs were proposed and the best fit for MDMC was selected. Before the movement, meetings with different departments were conducted and a movement plan was developed. The movement was conducted under the supervision of MDMC on 3^{rd} and 4^{th} of August. Workbenches were moved to new locations. Some equipment has been taken off the line. Air duct has been reworked to fit to the fume hoods. The production was smooth after the movement.

5.1.1 Proposed layouts

Following the guiding principles highlighted in the previous section, three different proposals were proposed. They can be summarized in the sketches and tables on the following pages. The lighter space is the space saved in each proposal.

Design A:

This design consists of 25 production benches distributed over 6 rows and saves an area of 476 ft^2. The new subassemblies' locations are labeled in Figure 5-1. This layout depends heavily on the supermarket decentralization principle (Chapter 4). It requires minor technical verification and minimal investment.

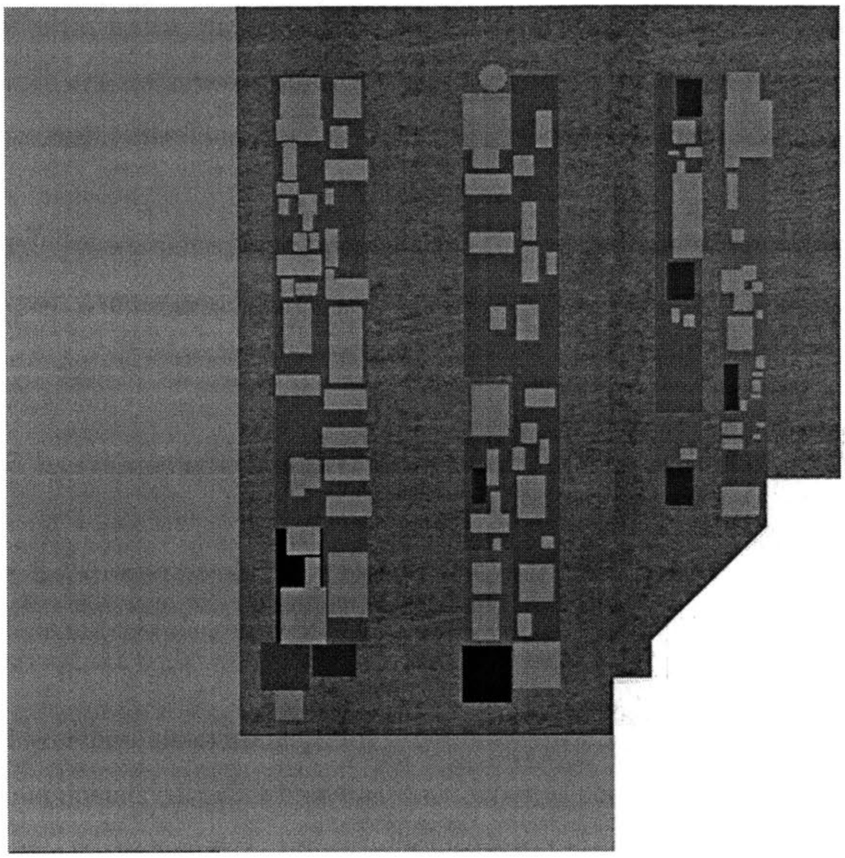


Figure 5.1: Design A

Table 5.1: Summary of Design A

Saved Area	No. of Production Benches	Ease of Movement	Potential technical Risk	Configuration
476 ft^2	25	Easy	Low	6 rows

Design B:

This design is shown in Figure 5-2 and consists of 24 production benches distributed over 5 rows and saves an area of 400 ft^2. This layout depends on the equipment sharing concept as well as the supermarket decentralization principle (Chapter 4). As shown in the product family matrix (Table 4.1), there is many tools and equipment that can be shared between the accessory and syringe subassemblies. Therefore, they were combined in one production line (the first one from the right) while keeping the rest of the subassemblies unchanged. Similar to Design A, this design requires minor technical verification and minimal investment requirements; however, it will result in reducing the production rate of both accessory and syringe subassemblies due to the shared equipment and tools.

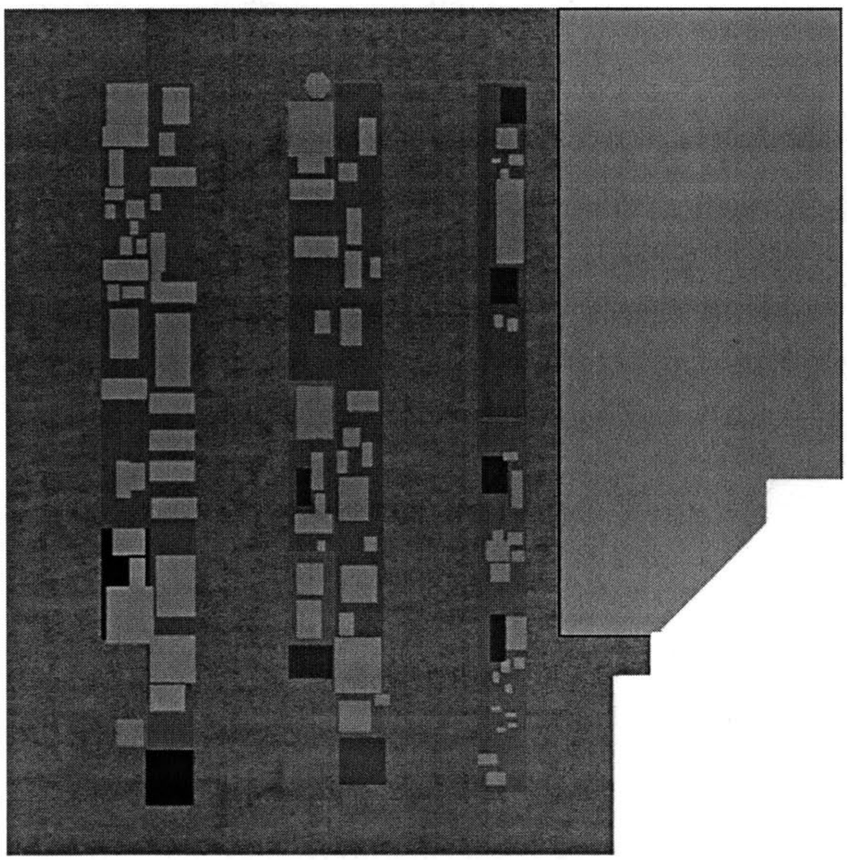


Figure 5.2: Design B

Table 5.2: Summary of Design B

Saved Area	No. of Production Benches	Ease of Movement	Potential technical Risk	Configuration
400 ft^2	24	Easy	Low	5 rows

Design C (U Shape Cells):

This design is shown in Figure 5-3 and consists of 25 production benches distributed over 4 cells and saves an area of 300 ft^2. This layout depends on the U shape cells concept as well as the supermarket decentralization principle. Unlike designs A and B, this design has major technical concerns and more investment requirements. The technical concerns will be mainly for the catheter subassembly because it requires a relatively long horizontal space that will be reduced significantly in this design. Moreover, the production rate for all subassemblies will be an area of concern that needs to be verified.

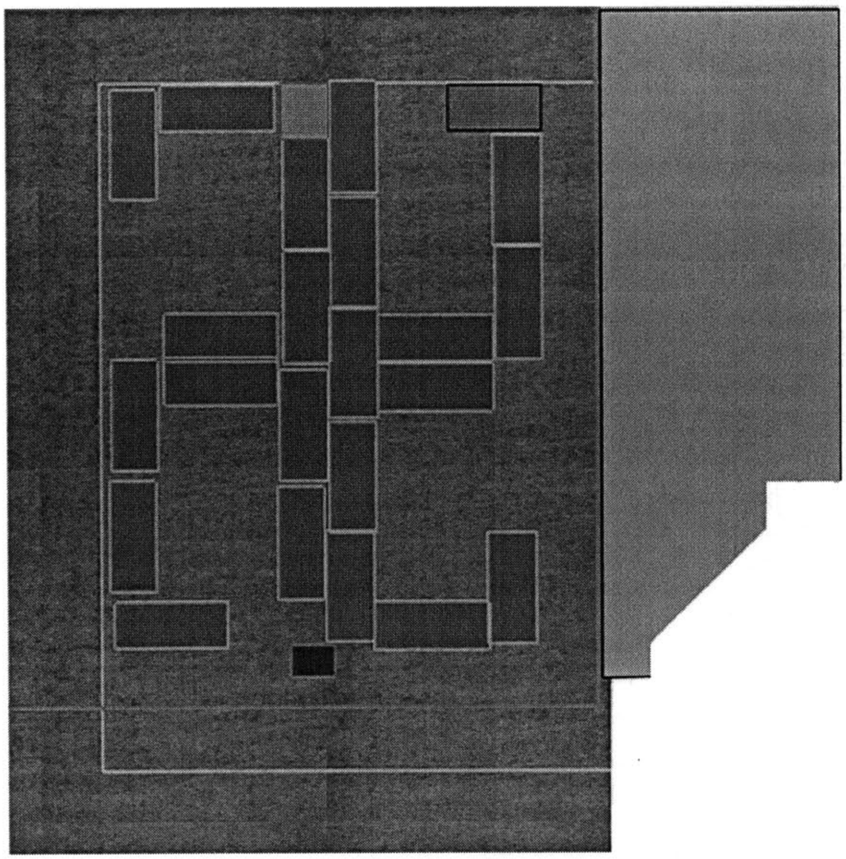


Figure 5.3: Design C

Table 5.3: Summary of Design C

Saved Area	No. of Production Benches	Ease of Movement	Potential technical Risk	Configuration
300 ft^2	25	Difficult	High	6 rows

5.1.2 Layout Selections

The three design proposals are compared and only one proposal is selected and reported to MDMC as the proposed design.

Design A

Advantages:

- Maximum saved area
- Better utilization of saved space
- Minimum cost
- Low level of movement
- Reducing maintenance time

Disadvantages:

- Low production area utilization rate
- More rows than other designs

Design B

Advantages:

- Maximum continuity of the lines
- Minimum movement
- Low cost

Disadvantages:

- Low production area utilization rate
- Hard to access and use the saved space

Design C

Advantages:

- Can be further improved to standing production line to further reduce area
- Better organization

Disadvantages:

- Hard to access and use the saved space
- Most difficult for movement
- High technical risk
- High cost for reconfiguration
- Hard to access and use the saved space

Since certain criteria weigh more important than others like accessibility of the saved space, ease of movement and potential technical risks, design A is chosen as a voting result within the team for its higher overall score. Design A is of low risk, easy for implementation and saves the most space. The projected layout of Design A with newly introduced production benches (golden blocks) is shown in figure 5.4:

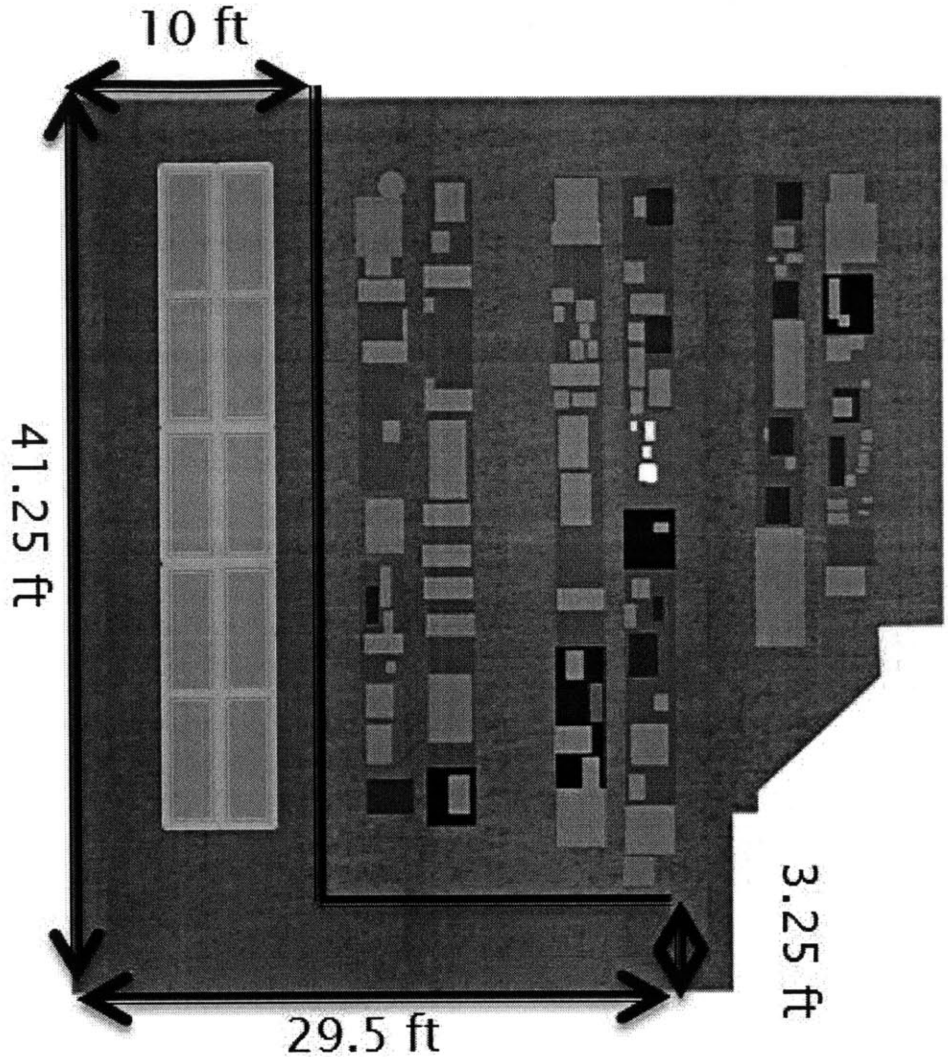


Figure 5.4: Design A with future production line

The proposed layout is using the same rule for numbering. The only difference is a prefix N is added to be distinguished from the original design. A matching table will be provided for the proposal to record the changes of benches.

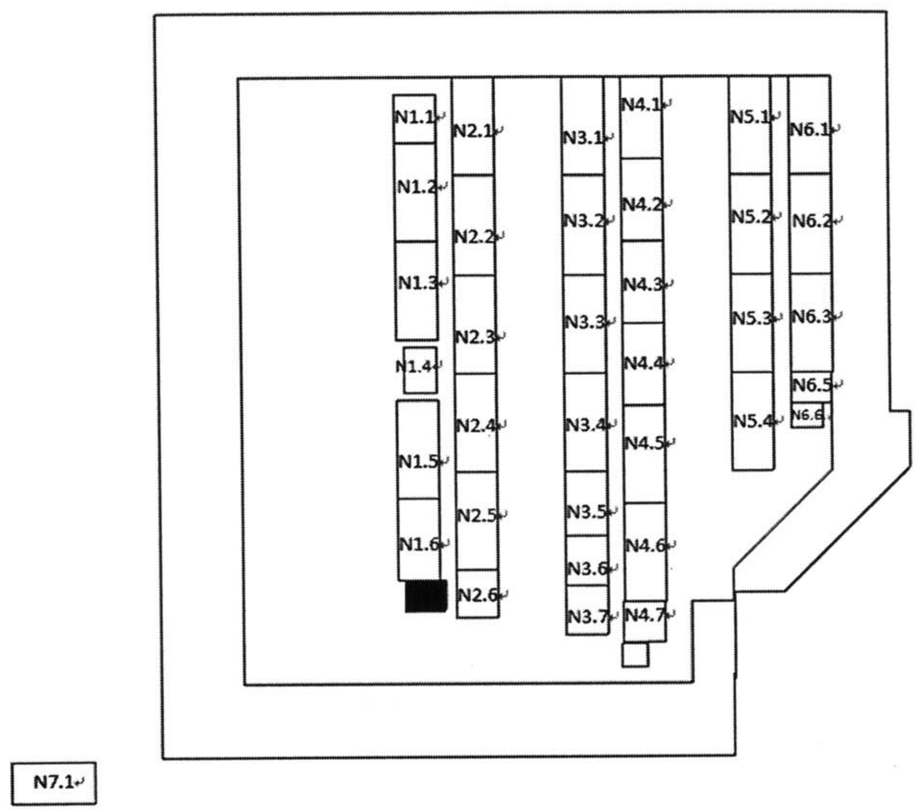


Figure 5.5: 2D Sketch of the Occlusion system Floor with the New Bench Labeling

The proposed layout 3D modeling is shown in Figure 5.6. Empty space has been cleaned out for potentially introducing a new production line.

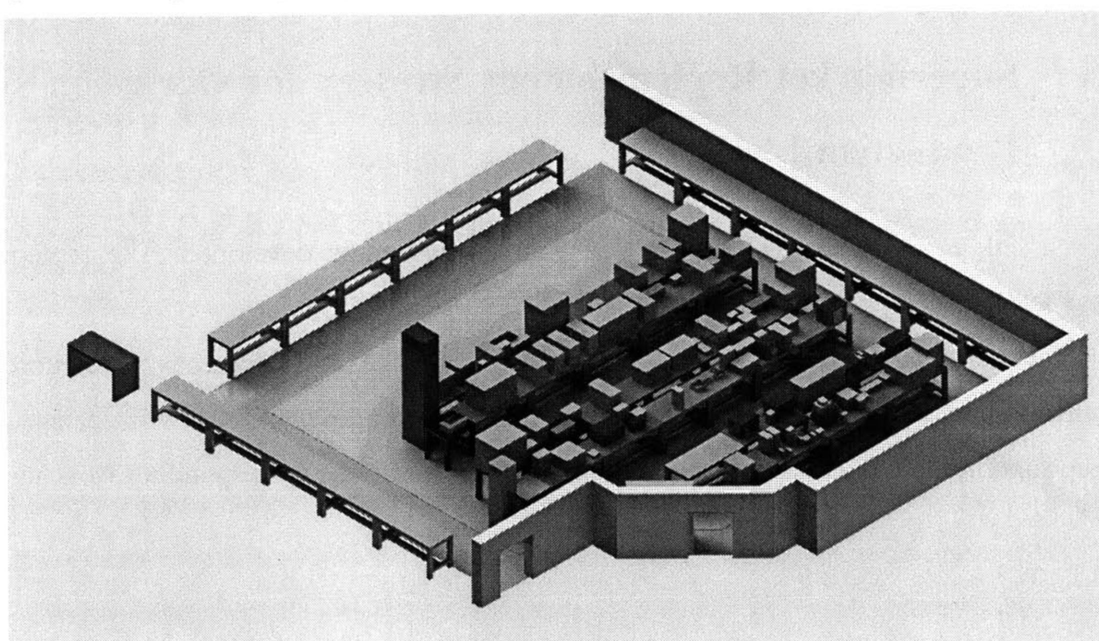


Figure 5.6: Proposed Layout Model

5.1.3 Movement Plan

In order to ensure smooth transformation process from the existing to the new layout, a detailed movement plan was prepared by the team that covers all the requirement and procedure. This plan provides the necessary numbering system, dimensioned drawings for current and new layout, needed items for movement, modifications description, new replenishment strategy, IQ and calibration requirements, and new layout bench details.

The plan consists of 62 pages, and part of it is included in the appendix

5.2 Inventory Optimization

Raw material inventory was analyzed and optimized on the production floor. The major step taken was decentralization of existing supermarket. Detailed analysis includes optimization of package size of decentralized supermarket replenishment, design of new Kanban system and detailed proposal of supermarket decentralization plan.

By the end of the project, the supermarket has been decentralized to point of use. The new Kanban replenishment system is used and related standard work is being developed. Part supplier has agreed on the proposed package quantity. After the adoption of new package sizes at the end of August, more than half of the current storage space for large containers will be reduced.

5.2.1 Supermarket Replenishment Strategy for Occlusion system Production Line

As discussed in section 4.2.1, the unified Kanban system is developed. The replenishment strategy is described as following:

The components for Occlusion system assembly, syringe and Accessory are stored in a centralized supermarket in the current design. The new proposed design will decentralize the existing supermarket and distribute component storage bins to the corresponding working bench.

Table 5.4 Briefing of replenishment strategy

Day 1	2:30 p.m.	Before leaving, production associates check supermarket supplies and place insufficient components' Kanban cards to the visual management cube.
	3 p.m.	Warehouse associate comes to the floor to collect the Kanban cards from the visual management cube and prepares the replenishment for the next day.
Day 2	9 a.m.	Warehouse associate replenishes those bins according to the bench number on the Kanban cards.

The proposed strategy discussed in Table 5.4 simplifies the replenishment process of the decentralized bins by gathering magnetic Kanban cards of empty or low part level bins to the visual management board at the end of the day. Since supermarket bins are decentralized, production associates will monitor the supermarket inventory level on their workbenches and give signals for replenishment at the end of the day. At usual afternoon inspection time (3 P.M.) the warehouse associate will take away the Kanban cards on the visual management board. Next morning, the warehouse associate will bring the inventory to replenish the bins according to the locating bench number on the Kanban cards. Gathering the Kanban cards in one location is easier for the warehouse associate.

5.2.2 Inventory Optimization Results

From the section 4.2.2 analysis of inventory, all the large packages located on the shelf are having excess inventory. The team focused on large package size parts and proposed an optimized quantity to the warehouse management team in table 5.5. A safety factor of N=3 was chosen and more than half of inventory storage space will be saved.

Table 5.5: Proposed replenishment packaging quantities

Stock No.	Description	Quantity of Pieces on the Floor	Proposed Quantity
1	Injection Molded Shell 1	126	60
2	Injection Molded Shell 2	182	60
3	Accessory Cover	672	150
4	Plunger	250	60
5	Injection Molded accessory 1	300	60
6	Injection Molded accessory 2	300	60
7	Injection Molded Base	300	60
8	Injection Molded Cover	300	60

The proposed package quantity has been accepted by part suppliers and the changes will be fully adopted by the end of August.

5.2.3 New Kanban System

Raw material supply system was standardized to Kanban system. Provided with the new strategy in 5.2.1, there is a need for each workbench to have a numbering flag to facilitate replenishment process. The numbering is for the proposed new layout and the color represents which subassembly it belongs to. An example of a print out of numbering flag is shown in Figure 5.7:

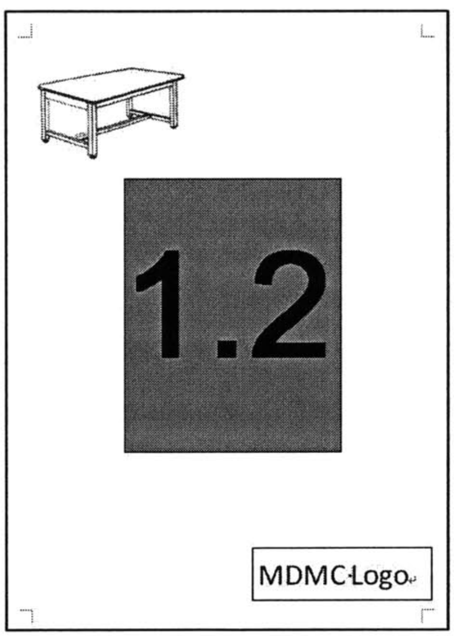


Figure 5.7 Bench numbering on each workbench (Row 1, bench 1.2)

New Kanban cards are color coated for easy recognition of the subassembly line it belongs to and will have bench number on them indicating at which exact workbench the bin is located. One example is shown in Figure 5.8:

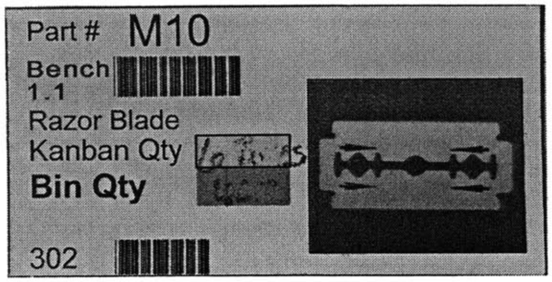


Figure 5.8 New Kanban card with color coding and bench number (Row-1, bench 1.1)

5.2.4 Supermarket Decentralization Implementation

Since decentralizing the supermarket to point of use is independent of reallocating of benches, the supermarket was decentralized before the final implementation of the new layout. The two supermarkets were decentralized on July 19th, 2012. The implementation was performed by three team members after the afternoon shift. Both the production line lead and the warehouse associate are informed of the details of this implementation and changes afterwards.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

A manufacturing system efficiency improvement package was proposed to MDMC. The package includes five concentrations:

Firstly, a new floor layout was proposed which will save a total of 476 ft^2 production space. This space can be utilized to introduce a new production line of 10 six foot benches. The flow of subassembly production in the proposed layout is still continuous. This design involves minimum disruptive changes to current daily operations.

Secondly, inventory onsite was optimized. An efficient supermarket decentralization plan was provided to put each safety stock bin from supermarket carts to the point of use. Different storage options were selected for each bin. A new replenishment strategy was proposed, which greatly improved the system level efficiency of the onsite inventory management. The new strategy saved the time for warehouse operator to replenish part supply bins. New package size for part supply was proposed to save more than 50% of the current big plastic container space. The supplier has already agreed on the proposed quantity and the new package size will be implemented in the coming weeks.

The other three improvements including manpower analysis, cycle time analysis and visual management are elaborated in the three theses by the other teammates.

Lessons learnt from this project:

Firstly, a specific problem in a manufacturing system is usually linked with various subsystems. In this project, the main objective is to reduce the floor space. However, to look at opportunities to reduce space we need to analyze the inventory and study the process flow. The inventory management system is also linked with visual management system. Before jumping into a problem, a plan should be developed on the system's level to guide the problem solving approach.

Secondly, project management is important in such a long time period project which requires inputs by different functions in the company. Meetings with warehouse associates, installation engineers and quality engineers need to be arranged properly. Possible delays also need to be taken into account.

Thirdly, line operators with rich firsthand experience provided a lot of valuable suggestions. Some suggestions are practical like the potential of combining two fume hoods. Some suggestions are not feasible due to some specific engineering process requirements. We considered all their suggestions and implemented the feasible ones. Taking suggestions out of the team and analyzing them using the team's knowledge is a short cut to come to preliminary practical proposals.

Last but not least, I learnt a lot from my supervisors and teammates. My supervisor at MDMC taught me the company standard way of solving problems. My teammates showed me different ideas and approaches while working on the floor space reduction concentration together.

6.2 Future Work

There are some areas not mentioned in the thesis related to this project that are worth future research and study.

New Production Line

As discussed in section 5.1.2, a new production line of 10 six foot long benches can be introduced to the emptied space on the floor. MDMC should consider which product assembly line to be moved into the area.

U Cell and working platform

The most spacing saving production line in MDMC currently is one U Cell working platform. Instead of sitting in front of workbench, production associates stand during work and will move from bench to bench. This design reduces aisle space significantly. However, this is more risky and complicated to implement. If the demand keeps dropping and another floor reduction project is needed. The U Cell would be a good direction of research. The current proposal has open ends which can be converted into U shape cell. The U cell layout needs to be carefully designed to reduce cost and keep the flow of production sequence. The working condition can be changed from sitting to standing for production associates to minimize the back-to-back distance between lines.

Improvement of Kanban System and inventory management

The current newly made Kanban cards are not all fit into the bin slot due to shortage of supply. Better cards can be made in the future. Fixtures underneath work bench can be installed to store big part supply bins to reduce the risk of falling and make it easier for access.

There is great opportunity in area reduction in the finished part inventory storage space. The subassembly lines are following both predicted production schedule and the Kanban system in the packaging area. Strictly following the Kanban system will eliminate the finished product storage onsite. On the other hand, since the production rate of the line is fixed and packaging is usually much faster than production, finished product onsite can absorb demand variations. There are two boxes of finished product inventory in the packaging area. Having a buffer inventory on production site might be useful to handle emergent events like quality issue and sudden increase in demand due to expiration of inventory in hospitals. An optimization between space reduction and ability to handle demand variation can be researched.

The global supply chain of this product is also a good research subject. The end user demand is difficult to obtain. An advanced model can be developed to predict demand more accurately to guide production and future reduces inventory cost.

Appendix

Asset list

Description	Asset Number	Dimensions	Bench	Voltage	Other Connections
Oven for Balloon	TD532820	27.5*25.3*35	1.1	Check	Check
Microscope	126736	13*29*20	1.1	110V	N/A
Laser Micrometer	TD581101	24.4*9*9.5	1.1	110V	N/A
Four Fixtures for Balloon	EQ1400C-F	8*13*8	1.1	N/A	N/A
EFD	EQ12400	-	1.1/1.2	110V	Air
Sander	EQ12361	-	1.2	110V	N/A
Ultrasonic Cleaner	EQ1242I	13*12*11.75	1.2	110V	N/A
Blow Machine	EQ1237K	9.9*6*7.9	1.2	110V	Air
Blow Machine	E-630	9.9*6*7.9	1.2	110V	Air
Panel on top of Blow Machine	TD53381A	11.1*8.3*4	1.2	110V	Air
Microscope	100301	13*29*20	1.2	110V	N/A
Blow Machine	E-630	9.9*6*7.9	1.2	110V	Air
Panel on top of Blow Machine	TD53541A	11.1*8.3*4	1.2	110V	Air
Spare Part for Fixture	N/A	8*14*4	1.2	N/A	N/A
Microscope Base	EQ2252B	24*18*18	1.3	110V	Air
Microscope Base	EQ2252C	24*18*18	1.3	110V	Air
Yellow Equipment	EQ2423D	6*6*18	1.3	110V	Air
Novacure Machine	EQ1464C	17*11*6	1.3	110V	N/A
Novacure Machine	EQ1464D	17*11*6	1.3	110V	N/A
Microscope with fixture A	89132	32*18*16	1.3	110V	N/A
Microscope with fixture B	126728	32*18*16	1.3	110V	N/A
Yellow Equipment	EQ2423B	6*6*18	1.4	110V	Air
Microscope	126676	13*29*20	1.4	110V	N/A
Laser Micrometer	TD58110V	24.4*9*9.5	1.5	110V	N/A
Tool Box	N/A	17*11*11	1.5	N/A	N/A
Nikon Measure scope	N/A	17*13*22	1.6	110V	N/A
Panasonic Image Equipment	N/A	20*10.5*12	1.6	110V	N/A
Ram Optical with Computer	EQ1256D	36*30*34	1.7	110V	N/A
Microscope with a fixture	126621	24*18*17	2.1	110V	N/A
Novacure Machine	EQ1464G	17*11*6	2.1	110V	N/A
Yellow Equipment	N/A	6*6*18	2.1	110V	Air
Fixture	EQ2252D	24*18*16	2.1	110V	Air
Microscope	126677	13*29*20	2.1	110V	N/A
Volume Static Eliminator	SDC011	13.5*11*10	2.1	110V	N/A

Heater	EQ2258C	6*14*4	2.2	N/A	N/A
Microscope	126734	13*29*20	2.2	110V	N/A
Microscope	126662	13*29*20	2.2	110V	N/A
Blow Machine	EQ1237F	9.9*6*7.9	2.2	110V	Air
Blow Machine	EQ1237I	9.9*6*7.9	2.2	110V	Air
Laser Micrometer	TD58110N	24.4*9*9.5	2.2	110V	N/A
Proofloader	58075	48*22*21.5	2.3	110V	Air
Microscope	100294	13*29*20	2.3	110V	N/A
Microscope Base	TD54093A	14*10*15	2.4	110V	Air
Microscope	126668	13*29*20	2.4	110V	N/A
Microscope	126738	13*29*20	2.4	110V	N/A
Microscope		13*29*20	2.4	110V	N/A
Seal Insertion Machine	126888	32*24*26	2.5	110V	Air
Chatillon	TD54887	9*4*2	2.5	110V	N/A
Microscope+Machine	126675	41*25*27	2.5	110V	N/A
EDM Machine	TD5325IB	26*26*39	3.1	Check	Complex
Medical Waste Container	N/A	dia: 17* height: 20	3.1	N/A	N/A
Pressure Regulaor	EQ1253E	7*8*4	3.2	110V	Air
Sander	EQ1236B	6*6*7	3.2	110V	N/A
Microscope	126729	13*29*20	3.2	110V	N/A
Microscope	126735	13*29*20	3.2	110V	N/A
EDM Control Panel	TD5325IB	12.3*17*18	3.2	110V	Complex
Ultrasonic Cleaner underneath the table	USC 169	22*31*18	3.2	110V	N/A
Alcohol-Air Supply	TD55786A	-	3.3	Check	Check
Automatic Cleaner	EQ1477A	14*10*5	3.3	110V	Air
Flushing Patency Space	EQ1305B	33*24*74	3.4	Check	Check
Laser meter	TD58110F	24*7*10	3.5	Not existing	Not existing
Plastic Fume Hood (thicker)	N/A	24*9*14	3.5	N/A	N/A
Humidifier	AOS001	14*7*18	3.5	110V	N/A
Microscope	126764	12*24*18	3.5	110V	N/A
Equipment	EQ1240L	7*6*12	3.5	110V	Air
Acids and Corrosives	N/A	20*18*21	3.6	N/A	N/A
Waste Rejected	N/A	24*16*18.5	3.6	N/A	N/A
Microscope in a fume hood	126181	24*11*14	4.1	110V	N/A
USC	USC 160	13*12*11.8	4.1	110V	N/A
Laser Micrometer	TD581101	24*9*14	4.2	Not existing	Not existing
Humidifier	AOS002	14*7*18	4.2	110V	N/A
Microscope in a fume hood	126664	36*19*19	4.2	110V	N/A
Shape Plug a	EQ1280B	23*14*8.5	4.3	110V	Air

Microscope	126730	13*29*20	4.3	Not existing	Not existing
Shape Plug b	EQ1453A	12*20*14	4.3	110V	Air
Gra Lab 545	N/A	10*4*5	4.4	110V	N/A
Epoxy Gray Box	EQ1240E	-	4.4	110V	Air
Air Blower	126619	12*10*8	4.4	110V	Air
Sheath a	N/A	27*18*13	4.4	110V	N/A
Sheath b	N/A	15.5*7*10.5	4.4	110V	N/A
Sheath c	N/A	14*7*18	4.4	110V	N/A
Sheath AB	N/A	-	4.4	110V	N/A
Fiber Optic Illuminator	N/A	7*5*8	4.5	110V	N/A
Sheath 2a	TD52533A	15.25*9*21	4.5	110V	Air
Sheath 2b	N/A	24*22*14	4.5	110V	N/A
Sheath 2c	N/A	8.5*8.5*3	4.5	110V	N/A
Plastic Fume Hood	N/A	24*16*16	5.1	N/A	N/A
Ultrasonic Cleaner	TD53862B	13*13*12	5.1	110V	N/A
Press Machine	EQ20871	6*10*19	5.1	N/A	N/A
Epoxy Black Tower, w/o Base	EQ1240G	3*6*11	5.1	110V	Air
Epoxy Black Tower, w/ Base	EQ1240A	7*6*12	5.1	110V	Air
Plastic Fume Hood	N/A	24*16*16	5.2	N/A	N/A
UV Curing Machine	TD51436B	54*18*27	5.2	N/A	N/A
Plastic Fume Hood	N/A	24*16*16	5.3	N/A	N/A
Slider Pad and Mid Pad	EQ1274D,E	8*6*4	5.3	110V	Air
Black Machine	EQ 1240U	7*6*12	5.3	110V	Air
Plastic Fume Hood (thicker plastic)	N/A	24*12*14	5.3	N/A	N/A
Press Machine	TD538221/01	6*10*19	5.5	N/A	N/A
Plastic Fume Hood	N/A	24*16*16	5.5	N/A	N/A
Testing Equipment	EQ1256G	20.5*20.5*26	6.1	110V	N/A
Accessories for Testing Equipment	N/A	7*9.5*7	6.1	110V	N/A
Inspection Computer and Monitor	N/A	36*30*18	6.1	110V	N/A
Fume Hood	N/A	28*11*14	6.2	N/A	N/A
Air Supply/ Press Control	EQ1253C	7*7.5*4	6.2	110V	Air
Equipment	EQ1465A	24*6.5*4.5	6.2	110V	N/A
Equipment Inside the UV Bonding	EQ2449A/ EQ1496A	8*9*9	6.3	110V	N/A
UV Bonding	UVH001	21*16*12	6.3	110V	N/A
EFOS Acticure	EQ1241C	12*11*6	6.3	110V	N/A
Pressure Control above UV Bond	EQ1253A	7*7.5*4	6.3	110V	Air
Equipment	EQ2170A	14*14*11	6.3	110V	Air

Top Gun on Stand Support	TD58103	5.5*4*7.5	6.3	110V	Air
Pressing Machine	EQ2087A	7*12*17	6.4	N/A	N/A
Pressing Machine	EQ2087B	7*12*17	6.4	N/A	N/A
Pressing Machine	TD 129877A	7*5*15	6.4	N/A	N/A
Fume Hood "Thick"	NA	30*9*14	6.4	N/A	N/A
Top Gun Shelf	TD50653C	7*5*5	6.4	110V	Air
Small Press Over the Shelf	EQ 2251A	2.5*6*4	6.4	N/A	N/A
Small Press Over the Shelf	EQ 2251B	2.5*6*4	6.4	N/A	N/A
Small Press Over the Shelf	TD53738A	2.5*6*6	6.4	N/A	N/A
Small Press Over the Shelf	TD53738B	2.5*6*6	6.4	N/A	N/A
EFD 2000 XL on Fume Hood	EQ1274	7.5*6*3	6.4	110V	Air

Floor Reduction Proposal Package

Abstract from package

This package summarizes the movement plan for the Area Reduction Project. The project's goal is to reduce the current floor area by one third. This package provides the necessary numbering system, dimensioned drawings for current and new layout, needed items for movement, movement descriptions, new replenishment strategy, IQ and calibration requirements, and new layout bench details. This area reduction plan suggests actions that will reduce the floor area used by the product by 31%. This layout will help to minimize the shift distance of the ducts to a maximal distance of 5 feet compared to 8 feet in the previous design. Movement descriptions summarize all movement and changes in the new layout and IQ requirement. In implementation of the new layout, the dimensioned drawings and new layout bench details provide detailed information on the arrangement of benches, equipment, and inventories.

Benches Labeling (Existing Layout):

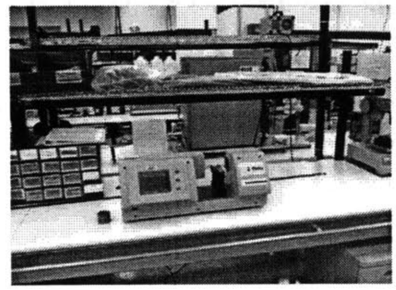
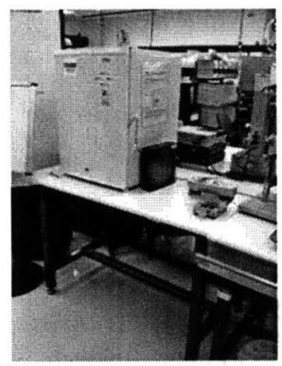
Table 1: Bench Labeling for Production Line

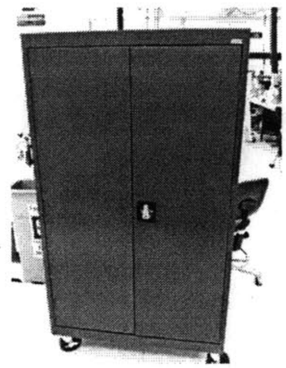
Process Description	Row Number	Benches, Stations & Cabinets (Current)	Benches, Stations & Cabinets (Proposed)
Catheter	1	1.1	N3.1
		1.2	N3.2
		1.3	N3.3
		1.4	N3.4
		1.5	N3.5
		1.6	N3.6
		1.7	N3.7
Catheter	2	2.1	N2.1
		2.2	N2.2
		2.3	N2.3
		2.4	N2.4
		2.5	N2.5
		2.6	Eliminated
Catheter	3	3.1	N1.1
		3.2	N1.2
		3.3	N1.3
		3.4	N1.4
		3.5	N1.5
		3.6	N1.6
Subassembly + Sheath	4	4.1	N5.4
		4.2	Eliminated
		4.3	N5.3
		4.4	N6.1
		4.5	N6.2
		4.6	N6.3
		4.7	Eliminated
Accessory	5	5.1	N4.3
		5.2	N4.2
		5.3	N4.1
		5.4	N5.1
		5.5	N5.2
		5.6	N5.5
		5.7	Eliminated
Syringe	6	6.1	N4.6
		6.2	Eliminated
		6.3	N4.4
		6.4	N4.5
		6.5	Eliminated
		6.6	N5.6
		6.7	Eliminated
Supermarket	7	7.1	Eliminated
		7.2	Eliminated
		7.3	Eliminated
		7.4	Eliminated
		7.5	N6.4
		7.6	Eliminated
Tensile Test	8	8.1	N7.1

Movements Summary

Moreover, Table 2 documents the changes that will take place on the affected benches (other than changing the location).

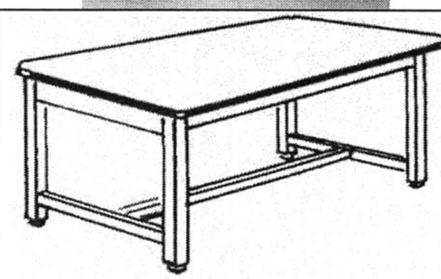
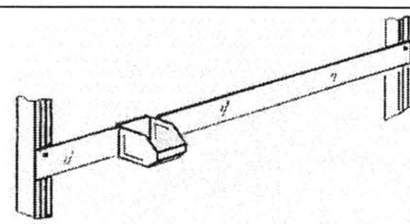
Table 2: Sample of Changes on Affected Benches

Item Description	Production Line	Bench No.	Action	Picture
Bench	Catheter	1.5	Replace the 6 ft. bench with a 4 ft. one.	
Fridge	Catheter	2.6	Combine it with the fridge at the coating room and eliminate its bench.	
Bench	Catheter	4.2	Replace the fume hood with a cone to be located on 4.3 and remove the 6ft bench (4.2)	
Working benches	Catheter	4.1/4.3	Replace these two benches (6ft) with two 5ft benches.	Refer to Figures 1 & 2.

Item Description	Production Line	Bench No.	Action	Picture
Cabinet	Sheath	4.7	Decentralize the content of the cabinet to 2 small drawers to be placed underneath bench (N4.2)	
Fume hoods	Accessory production line	5.5	Combine the fume hood with the one at 5.1.	
Bench	Accessory production line	5.4/5.5	Replace the 6ft bench (5.4) with a 5ft one. Relocate the benches 5.4 and 5.5 to their new locations shown in Figure 2 (N5.1 and N5.2 respectively)	
Computer Desk	Accessory production line	5.6	Replace it with the other computer desk (6.5) and relocate this desk to row 6 as shown in figure 2 (N6.3).	

Needed Items for the Movement

Table 3: Sample of Parts to be provided

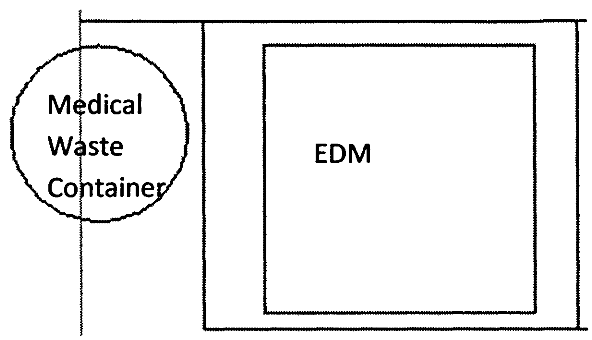
Item Description	Quantity	Picture
Fume Cone to replace the hood on bench	1	
Drawers	4	
3 ft. bench	1	
Bin Rail for 6 foot bench	3	

Saved Area

The Product Floor area will be reduced from 1528 ft^2 to 1052 ft^2 (31% reduction).

Sample of New Layout Bench Details

EDM Machine, Bench N1.1 – E831



Same bench, initially 3.1

Equipment

Description	Asset Number	Old Bench	Voltage	Other Connections	New Bench
EDM	TD5325IB	3.1	Check	Complex	N1.1
Medical Waste Container		3.1			N1.1

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