Hardy Diagnostics

Facility Redesign

By

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Abstract

This senior project is a facilities design for the plate production room at Hardy Diagnostics. This project was completed using a systematic layout planning approach. The main reason for this redesign was to consolidate all plate line production into one room. This would ensure better visibility for the managers. After the project was defined, the different departments were established and the relationships between those departments were found. The space requirements needed for those departments were then measured out to also include the aisle widths and any machinery or carts needed to complete each function. Having determined all requirements for this facility, three layouts were generated. The first layout is called the horizontal layout because of the direction of all of the plate lines. The second is called the vertical layout because all the plate lines are positioned vertically. The last is called the modified vertical layout because it is similar to the vertical layout with some modifications on plate line locations. After evaluating each layout, the modified vertical layout was chosen. The implementation costs about $3880 with a payback period of approximately 3 years.
Introduction

This senior project is a facilities redesign for a biomedical company called Hardy Diagnostics that is based in Santa Maria, CA. The facility consists of several production rooms where the company manufactures its high mix of diagnostic products. This company produces culture media that can detect and identify diseases such as strep and e. coli.

Currently there are three clean rooms for the manufacturing of plates. They wish to consolidate all the plate manufacturing into one room and free the other space for their tubes and bottles production areas. Hardy Diagnostics is experiencing increased customer demand and as a result production has increased in Santa Maria. There are even prospects of opening a manufacturing facility in Ohio. There are three major production departments, which include: plates, tubes/bottles, and reagents. They have expanded their product line to include new microbiological media and it has been added to the existing 3200 products. Expansion and re-allocation of the facility is required to accommodate this product line and the increasing demand.

Using a systematic approach to facilities design is an effective way of finding the best layout design. This approach is organized into a series of steps, which have been widely used in different kinds of layout designs. This approach can be applied to office, warehouse and manufacturing facility layouts. The steps include:
1. Define problem or goals.
2. Define departments
3. Define relationships
4. Space requirements
5. Develop alternative layouts
6. Evaluate layouts
7. Select layout
8. Define/Install/Maintain

By talking with, collecting data, and spend many hours observing the manufacturing director, and all those involved (production technicians), a thorough understanding of needs and data are gathered to create alternative layout designs. From these alternate layouts the best one is selected for implementation.

The main deliverables will include a CAD layout accompanied by relevant information and data, a report outlining the layout selection process, and a cost justification for implementation. Not defined in the scope are production efficiency improvements, storage of old equipment that will not be in the new layout, production floor replacement, and the layout design of other production areas. This senior project first addresses the background, literature review, design, methods, results, conclusion, bibliography and appendix.

**Background**

Microbiologists, Jay Hardy and Robert Shibata founded then named “Hardy Media” in 1980 in Santa Barbara. This is where they first started manufacturing quality media that
provides the nutrients necessary for culturing bacteria and fungi. After the company underwent rapid growth at a rate of 30% per year, more space was required and in 1991 they moved to their current location on 1480 McCoy Street in Santa Maria. At about the same time they changed their name to Hardy Diagnostics. The years following, the company opened six distribution centers across the United States, while keeping the main production in California.

There are three main production areas in the facility all considered clean rooms. Two rooms are dedicated to plate production and the third is for tubes and bottled products. Raw material (in powder form) is received, then as needed raw material is milled and mixed together in the Dehydrated Cultured Media (DCM) room. As the blended powders are released from Quality Control, powders are weighed and blended together as per batch record or recipe. A batch record is a step-by-step process that tells the operator how to prepare and manufacturing each product. The powders are then dissolved in de-ionized water then “cooked” in the kitchen to be sterilized. After products are cooled down, they are ready to be dispensed into plates or tubes. Plate products are usually dispensed on various plate lines. Tubes products may be dispensed with the tube machine or hand poured. Product then leaves the clean rooms with a few samples that go to QC to be tested, and then lastly released to be sold to customers. The product flow can be seen in the Appendix and the flow chart of this process is as follows:
Currently, there are 180 employees, of which 155 are based in Santa Maria. These Santa Maria employees are located in the 76,000 square feet headquarter facility. The plate room where the layout design takes place takes up 2400 square feet. All of the manufacturing takes place in this facility. In 2009, the company’s net profits were $2,070,000 and gross profits were $11,425,000.

The goal of this project is to not only consolidate the production areas to make way for new equipment, but to also satisfy employee preferences. The company is dedicated to producing as many quality products as possible, therefore creating an optimal clean room environment is integral for this layout design.

**Literature Review**

**What is facilities design?**

Customer satisfaction should be the most important aspect that any company should strive for. Many companies are similar to one another and perhaps the only defining aspect companies in the same industry have is the customer service they provide. A manufacturing organization must be able to meet the demands of their customer in a growing and expanding market. In a way a highly effective facility design is an integral part of maintaining a high level of customer satisfaction. Facility design defines the flow of product through a factory. A good facility design is able to push material out their doors into the hands of customers in a timely matter.
A facilities design planning must help an organization achieve a supply chain to maintain a competitive advantage. In addition to improving customer service, some other objectives of facilities planning include:

- Increase return on assets by maximizing inventory turns, minimizing obsolete inventory, maximizing employee participation, and maximizing continuous improvement.
- Reduce costs and grow the supply chain profitability.
- Support the organization's vision through improved material handling, material control and good housekeeping.
- Effectively utilize people, equipment, space, and energy.
- Be adaptable and promote ease of maintenance.
- Provide for employees safety and job satisfaction (Thompson).

Ideally a facilities design goes from the general to particular – from global location to workstation (Lee). For this particular application, the global site has already been determined. The micro and sub-micro space designs were considered for this project. That is, the placement of equipment and furniture in the facility and the individual workstations. On all levels it is important to be aware and plan according to the constraints of the facility. This includes the space, resources and relationships between entities. It is also important to design for continuous improvement for new product development, replacements for obsolete equipment and expansion.

On a macro perspective, there are five levels of facilities planning:

1. Global (Site Location) – This involves factors such as freight cost, labor cost, skill availability and site focus.
2. Supra (Site Planning) – This includes number, size and location of buildings. It includes infrastructure such as roads, water, gas and rail. This plan should look ahead to plan expansions and eventual site saturation.

3. Macro (Building layout) – Operating departments are defined and located at this level. Frequently, this is the most important level of planning. A Macro-layout institutionalizes the fundamental organizational structure in steel and concrete.

4. Micro (Work cell/Department Layout) – The emphasis shifts from gross material flow to personal space and communication. Socio-Technical considerations dominate.

5. Sub-micro (Workstation Design) – Here workstations are designed for efficiency, effectiveness and safety. Ergonomics is key (Strategos).

For the facility layout at Hardy, levels three through five will be applied because the site has been located and the only part of the building will be designed. This means levels one and two will not be applied here.

**What are some techniques and methodology for designing a facility?**

There are many different techniques for solving a facilities design problem. There are both qualitative and quantitative methods. In both cases there are very systematic ways to approach a facilities layout design. The Systematic Layout Planning (SLP) technique, which was developed in the late 1960’s is the most commonly used approach. This technique consists of four simple step-by-step phases and they include:

- Phase 1- Determination of the location of the area where departments are to be laid out: Phase 1 involves identifying the locations for the departments. This phase is the easiest of the four phases.
• Phase 2 - Establishing the general overall layout: This phase involves determining the flow of materials between departments, examining special adjacency requirements, determining the space required for each department, balancing it with the space available, incorporating practical constraints, and generating up to five alternate layout plans. The plans are evaluated based on cost and other non-cost considerations and a layout is selected for departments and general work areas.

• Phase 3 - Establishing detailed layout plans: The relative positions of departments found in Phase 2 do not provide details about the layout and location of each specific machine, auxiliary equipment, support services such as restrooms, cleaning rooms, and inspection station. This detailed layout of departments and support services is done in phase 3. The procedure for generating layouts in phase 3 are the same as in phase 2, except that phase 2 deals with the layout of departments, whereas phase 3 deals with the layout of machines and other auxiliary equipment in each department.

• Phase 4 - Installing the selected layout: The detailed layout must be approved by all concerned people: affected employees, supervisors and managers. Then the final layout is prepared. The drawings must show every possible detail because they are used to plan the move to the new facility. In phase 4, funds and time are appropriated for the moved and the actual relocation of machinery and services takes place.

The input data for these phases are classified into 5 categories:

• P (Product) – Types of products to be produced

• Q (Quantity) – Volume of each part type
• R (Routing) – Operation sequence for each part type
• S (Services) – Support services, locker rooms, inspection stations, and so on.
• T (Timing) – When are the part types to be produced? What machines will be used during this time period?

With this information charts and diagrams such as from-to material flow matrices, relationship charts and diagrams can be made (Heragu).

Another way to construct a facilities design is by using an analytical hierarchy process (AHP) and data envelopment analysis (DEA), which uses a computer aided layout-planning tool. In a case study using this method, these steps were taken to find the best layout:

• Step 1: Data collection – this includes the characteristics of products, quantities, routing, support, and time considerations in order to assure the validity of the input data at the design stage.
• Step 2: Layout alternative generation – this step adopts the computer aided layout planning tool, BLOCPLAN, to investigate a large number of design alternatives.
• Step 3: AHP for qualitative data evaluation – The purpose of the AHP is to provide a vector of weights expressing the relative importance of those layout alternatives for each criterion.
• Step 4: DEA for final design – The inputs and outputs of decision-making units are required information for DEA modeling.

From this case study there were 16 different alternate layouts generated from the computer system (Yang). This system proved to utilize the methodology. These two
approaches (SLP and AHP) have very similar techniques and produce the same results of finding the best layout design.

**What are challenges of facilities redesign planning and implementation?**

In a facilities redesign, it is important to have a plant that works efficiently while ensuring the safety of their employees (Usher). The plant needs to meet the needs of their customers while undergoing a remodeling project. The first step to any redesign layout is to understand how the current layout functions. Constraints like walls or columns are constraints when undergoing any modifications. Some challenges that might be faced during a facility redesign are:

- Changing the design
- Running out of money

These can be avoided by proper and adequate facility planning well before any implementation begins. With good planning, the results of the redesign may offer benefits for both the company and the employees.

**What is Culture Media? How is it used to Diagnose?**

All of the products at Hardy Diagnostics are used for the identification of different types of bacteria and microorganisms that are found in food, diseases, and even in human bodies. Culture media is the solution used for this purpose. Culture media or nutrient broth is a solution free of all microorganisms by sterilization but contains the substances required for the growth of a specific type of bacteria, protozoa, fungi or algae (Encyclopedia, 2011). There are two types of culture media: natural and artificial. Natural culture medium is found in nature and contains the necessary pabulum for the
development of or more species of bacteria. The most commonly used natural culture media includes blood serum, milk, and urine. Artificial culture medium is prepared artificially by adding nutritive material to water. The most useful artificial culture media are those infused with beef, mutton with the addition of a little peptone. There is another culture media that is the most commonly used culture media at Hardy. This solid culture media is agar and it is highly favorable for its isolation and differentiation of species (Sternberg).

Agar is the prominent medium used as Hardy’s diagnostic tools. Usually plated in standard sized Petri plates (or at Hardy, they are called mono plates), these agar products make up the majority of the company’s sales. Agar was originally founded in Japan and it was used as a dessert food item. The material’s origin begins as a sea moss and the moss is extracted with boiling water for several hours, and the extract strained through a sieve (Robertson). The congealing to jelly form gives the agar its unique consistency.

**What is a clean room?**

Because Hardy Diagnostics is a manufacturer and distributor of biomedical culture media and tools, it is essential for this company to comply to and use federal regulated clean rooms. A clean room is basically a room that is clean however according to the International Organization of Standardization (ISO), a clean room is a “room in which the airborne particles are controlled, and which is constructed and used in a manner to minimize the introduction, generation, and retention of particles inside the room and in which other relevant parameters, e.g. temperature, humidity and pressure are controlled as necessary” (Whyte). By using this standard biomedical companies like Hardy must work in a specific type of class of clean room. The purpose of using clean rooms is simply to ensure
no contaminants enters the product. The products that come out of Hardy are highly sensitive to bacteria and other pathogens floating in the air. By using clean rooms, the risk of contamination is drastically decreased.

Because cleanrooms house the production of most of Hardy’s products, environmental monitoring is important. The quality assurance department at Hardy has two biologists who periodically monitor each of the clean rooms in the facility. The clean rooms must meet the standards according to the FDA. Therefore, to evaluate the performance of the cleanroom properly in controlling internal contamination, tests must be conducted at critical areas within the facility. Samples must be done with a light scattering particle counter, providing a high rate of sampling (Gladstone). These samplings should be done with the room in full operation and occupied with operators. Other tests, such as temperature and humidity gradients, lighting levels are often required in evaluating the performance of a clean room facility.

What is clean room manufacturing?

Sterile manufacturing has come a long ways in the last 30 years. In 1977, sterilization by using moist-heat was highly debated whereas today this method with the use of autoclaves is used almost universally in the biomedical industry. In 1984, the US FDA started drafting the Guideline on Sterile Drug Products Produced by Aseptic Processing (Akers). This required the industry to have a more reliable sterility test. Sterile manufacturing environments have become more standardized in the United States. As technology advances, the risk of contamination in sterile environments decreases and perhaps in the next 20 years sterile processes may be completely automated. Automation
would allow for processes to be performed with the lights off, which would be very good for the carbon footprint and contamination control (Akers).

In the biomedical industry, products must be fabricated in an environment free of particulates in the air. Clean rooms are used for this application and the use of HEPA filters help maintain a low level of environmental pollutants. HEPA, or high efficiency particulate air filters are widely used in clean rooms not only to collect dust and mineral particles of biological origin including particles directly or indirectly emitted from living organisms especially airborne microorganisms (bacteria, fungal spores) and pollen (Cao). To maintain a clean environment, HEPA filters must be working properly and have a clean air flow throughout the facility.

There are some factors that may affect the airflow of a clean room. It is important to understand and manipulate the flow of air in the clean room because dirt and dust contamination are highly undesirable. The clean room becomes a controlled environment where the distribution of airflow follows a proper pattern and temperature (Cheong). Air flows nominally at a uniform air velocity down from the HEPA filters. Furniture such as equipment or clean benches influences the flow of air. Contamination of product may be stopped by strategically placing furniture around the room. Simulation software may be used to emulate the airflow characteristics of a clean room with the influences of furniture.

**Design**

In January 2010, Kimball Lombardi, an industrial engineer was hired as the manufacturing director to spearhead many projects to reduce waste, increase quality and increase productivity. A facility redesign had always been speculated but nothing was set in
stone. Over the summer, talks of a facility redesign were reignited as the author came into the company as an intern. Her task was to initially take time studies and write work instructions. Facility layout design was an expressed interest of the intern. This was a great opportunity for the company to go through with the overdue facility redesign. This facility design would consist of a new layout of the plate production room. The previous layout is shown in the Appendix. Plate line 4 is shown in this layout but is removed for the new layout because it is rarely used.

The time studies taken allowed for better understanding of plate production on the manufacturing floor. Several issues surfaced as potential improvements. After the product has been sterilized it moves into the plate production room or the South Wall Production room. The media is prepped with supplements if needed then aseptically poured into petri plates. These plates are then stacked and packaged in groups of ten. Next the plates are packaged and stored until sold to customers. Product travel time varied from machine to machine. Higher volumes of culture media can be produced on plate line 8 but this plate line is the farthest from the kitchen and storage area. More varying products are produced on plate line 5 but less yield is produced and this plate line is much closer to the kitchen and storage area than plate line 8. These plate lines are detailed under the departments section.

All 6 of the production machines were in three different clean room locations throughout the entire facility. Four plate lines resided in the plate room (the focus of this layout design). Three of the four plate lines are used daily where plate line 4 was used approximately once a month. This line was only used to pick up the slack from the other plate lines if needed. The largest and fastest plate line, Line 8 was in the South Wall
Production room. Finally the smallest plate-dispensing machine was in a small room, which is called the boutique room. The new layout includes all of these machines except for plate line 4 because the machine was not as productive as the other plate lines. The layout design is improved by using the Systematic planning procedure, which is as follows:

1. Define problem or goals
2. Define departments
3. Define relationships
4. Space requirements
5. Develop alternative layouts
6. Evaluate layouts
7. Select layout
8. Define/Install/Maintain (this will be covered in the Implementation section)

**Problem Statement**

A facility redesign is needed due to a desire to consolidate all the plate manufacturing lines into one room. This consolidation allows for better supervision and communication between managers and production technicians. In addition to better visibility of this manufacturing floor, there is less travel time of product from the kitchen area to the plate lines.

This project redesigns the plate production floor to meet the specifications of the company needs, workers’ ability to adjust to the change, and space requirements. All plate lines must be in a clean room to maintain the sterilization of the culture media. Operators must wear the appropriate personal protective equipment such as Tyvek gown, safety glasses, bouffant cap, facemask and Latex gloves.
Planning Departments

For facilities planning, a department is defined as a group of workstations. The departments for this project are defined below. Many of the departments are independent of each other because typical material flow comes from the kitchen to one of the plate lines to storage, and then out to packaging. Individual stand-alone machines defined the departments in this layout design. The main departments are the plate lines themselves. There are usually two operators per plate line. One person is loading empty plates into the plate dispenser and the other person does a quick visual inspection of the plates then packs and seals the plates into plastic sleeves. The dispensing and stacking of plates are completely automated by using are series of motion sensors. The automation of each plate line is different from one another.

As the plates are being dispensed, an operator will take samples from the beginning, middle, and end of the production run to send to quality control to ensure correct specifications. Excluding plate line 8, all plates produced are packaged the following day into boxes of 250 plates or 25 sleeves. All plate lines have a Plexiglas cover over the conveyor belts fitted with HEPA units to maintain a clean environment. For packaging purposes the plates are stacked into groups of ten, then packaged into a plastic bag, which is then sealed closed while the product label is placed on the bag. The product is usually sold as the individual sleeves to the customers.

Each of the plate functions requires several extra components, which include a sealing machine, a supply cart, a cart with empty plates and a cart to store finished product. The supply cart contains several items required for production such as heat pads (to keep
media at the appropriate temperature and mixing), latex gloves for the operators, zip ties for the pumps, bags for packaging and anything else required for the individual plate lines

**Plate Line 2**

This is the oldest functioning plate line in facility (approximately 20 years old) and it produces the large H-plates. These plates are 150 mm in diameter compared to the more typical 100 mm diameter mono plates. Because of the sheer size of these plates, the media takes a longer time to set up. The plate line has two adjacent conveyor belts going in opposite directions. The media is poured on one side then the plate travels down the length of the conveyor then gets kicked back on the second conveyor. The plates are stacked in sets of ten then the operator bags and seals the plates.

![Figure 3: Line 2 Production with mobile HEPA](image)

This plate line only has one operator because the conveyor belts run slower compared to other plate lines and only one plate is poured at a time. The operator replenishes the magazine that holds empty plates when he sees that the supply is low. At the bottom of the magazine, the large plate is pushed through to the media-dispensing pump. The lid of the plate is opened and media is poured in then it is pushed out to the conveyor. Because of the sheer size of these plates, this plate line produces 720
plates per hour. When the plate has traveled the length of the conveyor and back it is pushed through a labeler and light. The light is for the operator to quickly visually inspect the color of the media. The plate then slides down to a stacker where it is stacked to ten plates then pushed out to the operator’s table. The operator then bags the stack of ten and then seals the bag. This sleeve of plates is then stored on a cart until the product yield is met, when the cart is then pushed out of the cleanroom to the packaging area.

**Plate Line 5**

This plate line sees the most variety of products. It is second to plate line 8 in speed and yield. There are two types of plates that can be produced on this line. The regular mono can be manufactured here and also the bi-plate, which is the same size as the mono but has a separator down the middle to hold two different culture mediums. This plate line is the second fastest because it dispenses three plates at a time. For a mono plate, there are three pumps that the culture media dispenses through. For a bi-plate, there are six pumps (three from one pot and three from another) that dispense into the corresponding sides of plates.

Similarly to plate line 2, the bottoms of the plates are pushed onto the dispensing area and then the lid is pushed over after dispensing has been completed. As the lid is being replaced the entire plate is pushed onto the conveyor belt. The conveyor belt is about 27 feet long and travels much quicker than plate line 2. When the plates reach the end of the belt, the three plates are pushed in the perpendicular direction to be labeled and shined with light for the operator to do a quick visual inspection. The plates then travel to a stacker where it is again stacked in groups of ten. This plate line produces 1200 plates per hour on average. When the stack is completed the plates are pushed onto a table where the operator takes the stack, bags and seals it. These completed sleeves are stored on a cart
until the run has finished and then the cart is pushed out to the packaging area. The same process is practiced for bi-plates.

Unlike plate line 2, there is no mobile HEPA unit over the front end of the plate line. However there is a hanging HEPA above the dispensing area. This helps reduce contamination. This plate line could be its own department but further breaking it down into the front end and back end operating stations is more specific because each station has very different roles for running the plate line. However, before any product is run on this line, both operators set-up the plate line according to the specifications of each individual plate line. The set-up of the plate line for production includes the connecting of the reactor or pot to the pumps, setting the speed of the conveyor, the pouring rate, checking the pH level and signing off on batch records. Below is the description of both stations on this line.

**Front End Operating Station**

This operator refills the plate magazines with empty plates. There are three magazines that feed empty plates onto the conveyor. These are the three positions where media is poured. The operator will also periodically check the fill amounts of each of the positions throughout the production run.

Another function this operator does is monitoring the reactor or pot of media. He checks the temperature of the media to see whether the media level is getting low. In the reactor or

Figure 4: Operator refilling plate magazines with empty plates
pot, the media is held at a constant temperature of 45 °C and constantly mixing with either a stir bar (in pots) or a built-in mixer (in reactors). When the temperature drops, this is a good signal to tell the operator the amount of media inside is getting low. When air bubbles appear in the tube set connection, then the production run is over and the operator disconnects all tube sets and takes the used tube set and media receptacle out of the plate room to be cleaned.

*Back End Operating Station*

This workstation is located at the opposite side of the plate line. After the media has cooled and hardened the plates are passed over a light where the operator does a quick visual inspection of all finished products. The operator checks for inconsistencies in the product such as chips, air bubbles and discoloration. After the plates pass over the light, they are stacked into groups of ten then pushed aside. The back end operator takes the stack of ten and packages them into a plastic bag and then seals them with a heat sealer. A label is placed on the bag with information about the product name, catalog number, expiration date and other crucial information. After sealing the bag, the sleeve of plates is placed on a finished goods storage cart.
This operator is also responsible for gathering samples for quality control. Typically ten plates are taken from the beginning, middle and end of the production run. The QC samples are placed in bags with labels but not sealed. These plates are consumed in the QC department because the samples are tested for functionality.

**Plate Line 7**

This is a unique plate line because two different sizes of plates can be produced on this line. There is the typical mono and there are G-plates, which are smaller in size. It is 60 mm in diameter as opposed to the 100 mm mono plate. The plate line has a magazine adapter for the mono and the G-plates. This plate line is similar in size to plate line 5 but it has two conveyor belts like plate line 2. This plate line can dispense three plates at a time for both the mono and G-plates. On average 1200 plates can be produced in an hour.

The dispensing process is different from line 5 and 2. Instead of the lids sliding off there are suction cups that remove the lid and place it on the line in front of the plate. The bottom of the plate is then slid onto the conveyor after the lids are dropped. Then the three pumps travel and dispense at the same time the plate advances on the belt. The pumps then reset to the starting position to dispense for the next three plates. Before the plates reach the end of the conveyor belt a motion sensor activates a set of suction cups to place the lids back onto the plates. The plates are pushed in the perpendicular direction to a stacker. As the plates pass into the stacker, they are labeled. After being stacked in a group of 10 the plates

*Figure 7: Line 7 front-end operator*
are pushed onto a conveyor going in the opposite direction from whence they came. These plates travel all the way back to the operator who is replenishing the empty plates. The operator must then bag and seal the plates that have traveled back to her. This plate line is meant for one operator but there is, on occasion an additional operator by the stacker doing a visual inspection of the plates and manually stacking the plates when the automatic stacker is broken.

The two operators for this plate line have differing roles. Similarly to plate line 5 both operators are positioned on opposite sides of the line, but they both contribute to the set-up of this plate line for a production run. Again, the set-up includes, connecting the media receptacle to the pumps, checking the pH, checking the fill amounts, setting the speed of the conveyor, setting the pour rate, and signing off on the batch records.

*Front End Operator Station*

This position does all of the same functions as the front-end operator station on plate line 5. However, the stacked plates do return to this position and therefore this operator must also seal and label the finished plates.

*Back End Operator Station*

The operator at this position does the visual inspection when the plates pass over the light to the stacker. Often times the stacker may malfunction, so the operator manually stacks plates of ten and places it onto the return conveyor. This stacker is known to break down
at least once a week. The main purpose of this position is to make sure the automation at the back end of the plate line does not fail and if it does fail she must be able to make adjustments to ensure the production runs smoothly without any stoppage time.

**Plate Line 8**

This is company’s largest yielding and fastest plate line. 10,000 plates can be produced in 3 hours on this plate line. Instead of 3 plates being poured at once, this plate pours 8 plates at once. This line is considerably wider than the other lines therefore it takes up more space. This plate line also pours and stacks 8 sleeves at one time, which is the main reason this plate line is so fast. This plate line has a unique function that the other plate lines lack. This plate line has it’s own auto-bagger. That is, it takes the queued stack of plates then bags, seals and labels the sleeve of 10 plates. There is an operator who packs the sleeves into the same boxes described in the packaging process. The main dispensing process on the plate line requires a clean room environment but the packaging process does not. Originally the packaging function presided in the adjacent room, which was not in a clean room environment. However the auto-bagger that was in the non-clean room needed to maintain a clean environment. To maintain this, a hanging HEPA with curtains that reached the floor was fixed above the auto-bagger.
Due to the high volume of product coming off of this line, it is not uncommon for operators to take breaks (while other employees take over for a period of time). Unlike the other plates lines there are three operators required to run this plate line.

*Front End Operator Position*

At this position the operator conducts the same operations as specified in front end operator position on plate line 5. This high-speed plate line requires more attention for the operator because the plate magazine requires more frequent replenishment. Again this operator must check the reactor temperature and the fill amount for all 8 pump positions periodically throughout the production run.

*Back End Operator Position*

This operator, very similarly to the Line 7 back end operator, must visually inspect the plates as they pass over the light. He must also collect samples for QC. In some cases, the auto-bagger malfunctions so it is the job of this operator to take the plates out of the stacker and place the finished plates on a storage cart.
This allows the plate line to continue to run while a maintenance worker fixes the auto-bagger.

**Packer Position**

After the sleeves of plates have been bagged, sealed and labeled, there is no automation for placing the sleeves into a box for warehouse storage. An additional person is needed for this operation. This operator takes the sleeves and simply packs them into boxes and stacks those boxes on a pallet. This operator also monitors the auto-bagger and all the automation that goes into the packaging function of this production line. This operator isn’t needed in the set-up of this plate line.

**AES**

Another unique production equipment is the AES machine. This machine is used for small production runs (usually 200-600 plates) and only needs one operator. This machine has a carousel where the operator places a stack of empty plates. The carousel rotates and a single plate drops down into the dispensing area. The single plate is positioned, the lid is lifted, media is poured in, and the plate moves to the next slot where it is labeled. Then the plate moves around back into the carousel and stacks up where the operator can take the finished stack out of
the carousel. With the stack of 20 finished plates the operator separates them into stacks of ten to bag and seal the plates similarly to the other plate line functions. This operation took place in a separate clean room called the boutique. The new layout must account for the space requirements needed for this function, as it will now be located in the plate room.

**Clean Bench**

Although not used on a regular basis, this clean bench is required for some small tasks. One function includes the pouring of blood into smaller vials that are sold individually. Another function is the need for an egg yolk base in some products. The clean bench is used for the staging area for cracking and separating the eggs. This clean bench is required to be in this room because it needs a clean room environment. Also, the QC department uses this area for some of their functions, which usually takes place after production is done for the day.

**AnaeroGro Sealer**

A new line of product has been introduced at Hardy Diagnostics and it has a very unique type of packaging requirements. This line of products is pre-reduced culture media that is packaged in an oxygen free foil pouch. A special sealer is used to ensure the plates are packaged into the pouches free of oxygen. Each pouch is fixed around two
nozzles on the sealer. One of the nozzles vacuums all air in the pouch and the other nozzle fills the pouch with nitrogen and then the sealer quickly clamps down while the nozzles quickly retract away from the sealer.

Computer Stations

For the plate lines 2, 5, 7, and the AES, there is a computer station where the operators can check for the day’s schedule and other requirements. A separate computer station is needed for Line 8. This computer is located in a different area.

Quality Control pick-up

For all the quality control samples, there is a designated box that has a door on the inside and outside of the plate room. From the inside the operators can place the plates in this box without having to leave the plate room. A technician from QC can then open the door on the outside of the plate room and obtain the samples for testing.

Finished Goods Storage

After plates have been produced and the sleeves are placed on carts, the filled carts are wheeled to one area of the plate room. This area is where the sleeves are stored until it is ready for packaging into boxes. Plates will stay in this area until the following day.

Raw Material – Empty Plates Storage

Additionally, there are empty plates that are stored in this room. Usually there is a full day’s worth of plates for each plate line to pull from. If there is a shortage, an employee is called to restock a storage cart.
Soft Wall Corridor

The purpose of this area is to create clean room environment between the two clean production rooms. This solves the issue of operators having to un-gown and re-gown to travel between the two clean rooms. No HEPA filters are used for this soft wall corridor, just the positive area overflowing out of the plate room and the south wall production room will produce a clean room buffer. This area will also store the finished goods of plates from the plate room. This is temporary storage because the plates are packed into boxes the day after they are manufactured.

Vestibule

This is a buffer between clean room and non-clean room. This vestibule is a hanging curtain that is placed over the east door. No HEPA is required for this vestibule, but it does keep some of the dust particles from outside the plate room out. This door is often used for restocking the empty plates storage. A cart is pushed through the door so that no un-gowning or re-gowning is required between the two areas.

Relationships

Because separate products are produced simultaneously on different lines, the plate lines and AES machine do not rely on each other. That is, when a product is being manufactured it does not go through plate lines or the AES. However, each line produces QC samples throughout each production run, therefore there is a direct relationship between each plate line and the QC sample drop box. Also, there is a direct relationship between the each of the plate lines to storage. There is a direct relationship between the
plate lines and the computer workstations. Because the operators need to check the computer for information, there is a need to travel to and from the computer station.

There are a few relationships between some of the other departments in this room. For example, the AnaeroGro sealer receives plates from either plate line 7 or plate line 5. The plates found in the AnaeroGro products are produced exactly the same way as the typical products but the sealing process is different. After the products have been sealed, these pouches are placed onto a cart and added to the storage area in the plate room. This is another relationship between the AnaeroGro and storage. Although many of the clean bench functions are independent, there is one function that requires a relationship between the clean bench and line 5 and line 7. It requires the cracking of eggs and the transportation between the clean bench and either line.

The relationship chart is shown in the appendix. The relationship chart includes everything except the soft wall corridor because this area does not aid in production.

**Space Requirements**

The next step in this systematic layout approach is to determine the space requirements for each department. By determining the space requirements for each department, preliminary steps can be taken to create different layouts.

In addition to these main departments space requirements for other areas such as walkways and doorways are important to consider. According to OSHA requirements, walkways and doorways must be 3’ in floor space. There are 6 doors in the plate room and there must be three feet of clearance on both sides of the door. It is also important to ensure that the reactors can pass easily through the room and moved to their designated areas. The reactors range from 50 liters to 400 liters. The largest reactor is about three feet
in diameter. The walkways need to accommodate the space needed for these large reactors and it is required to have enough space for an operator to pass by and adjust the different knobs and controls on the reactors. For each plate machine excluding plate line 8, the back end operator must seal the packaged plates in their bags. These sealers are about 2.5’ x 2.5’ but they can be moved because they are mobile. There are also carts on casters that are 1.5’ x 4’. These carts are used for the storage of finished goods and also the storage of empty plates. Throughout the facility these carts are found at the front and back ends of each plate line. Tabulated below is the break down of space requirements for the layout:

**Table 1: Space Requirements**

<table>
<thead>
<tr>
<th>Department</th>
<th>Spaced Required</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plate Line 2</strong></td>
<td>28’ x 3.5’ = 98 ft²</td>
</tr>
<tr>
<td>• Sealer</td>
<td>2.5’ x 2.5’ = 6.25 ft²</td>
</tr>
<tr>
<td>• Empty plate cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Supplement cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Finished goods cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Aisles</td>
<td>3’ around</td>
</tr>
<tr>
<td><strong>Plate Line 5</strong></td>
<td>32.5’ x 2’ = 65 ft²</td>
</tr>
<tr>
<td>• Sealer</td>
<td>2.5’ x 2.5’ = 6.25 ft²</td>
</tr>
<tr>
<td>• Empty plate cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Supplement cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Finished goods cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Aisles</td>
<td>3’ around</td>
</tr>
<tr>
<td><strong>Plate line 7</strong></td>
<td>37’ x 2.5’ = 92.5 ft²</td>
</tr>
<tr>
<td>• Sealer</td>
<td>2.5’ x 2.5’ = 6.25 ft²</td>
</tr>
<tr>
<td>• Empty plate cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Supplement cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Finished goods cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Aisles</td>
<td>3’ around</td>
</tr>
<tr>
<td><strong>Plate line 8</strong></td>
<td>35’ x 3’ + 11’ x 9’ = 204 ft²</td>
</tr>
<tr>
<td>• Empty plate cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Supplement cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Finished goods cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Aisles</td>
<td>3’ around</td>
</tr>
<tr>
<td><strong>AES</strong></td>
<td>111 ft²</td>
</tr>
<tr>
<td>• Sealer</td>
<td>2.5’ x 2.5’ = 6.25 ft²</td>
</tr>
<tr>
<td>• Empty plate cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
<tr>
<td>• Finished goods cart</td>
<td>1.5’ x 4’ = 6 ft²</td>
</tr>
</tbody>
</table>
A summary of total space requirements can be found in the Appendix.

Alternate Layouts

In order to find the optimal layout design for a facility, alternate layouts must be designed. Often times one layout can reveal some obstacles that another layout would otherwise disguise. There were many things considered for the formulation of the different layouts. The relationships defined earlier are the most prominent resource however the opinion and preferences of the operators are also considered for the designs.

It is also important to note the flow of product going through the room. It is ideal to have the culture media in pots or reactors come in through one door and finished goods going out of another. In addition to the relationships, the space requirements also need to be considered for the plate lines, storage carts, sealers and the operators. The biggest differentiations between the proposed layouts are the locations of the large plate lines. The other departments are also important but do not require taking up the majority of plate room floor therefore these departments will remain along the walls of the room.
Alternate Layout 1: Horizontal Layout

This layout called the horizontal layout based on the general direction of the plate lines. Also shown is the flow of materials on each plate line. The previous manufacturing director proposed this layout. The idea for this layout was based on the flow of material coming in from the doors on the left. The doors on the left both lead to the kitchen. The
kitchen is the staging area for the culture media and where it is sterilized in either reactors or autoclaves. As the media receptacles flow from the kitchen into the plate room, the finished plates would then flow out of the door on the bottom right where it would later be packaged. The large plate line 8 is positioned along the northern most part of the room. The logic behind this is to keep the out-feed of plates to the auto-bagger outside of the plate room since it does not require being inside the plate room. Arrows indicate the flow of the product on each plate line. Lines 2 and 7 show there is a kick back to the starting position. The northern wall and the eastern wall are the only locations that plate line 8 can reside.
This layout shows that all of the plate lines are perpendicular to the proposed alternate layout 1. Because of this positioning the layout is called the vertical layout.

For each of the plate lines, the front-end operators are all on the same side of the room. This allows reactors to all come into the room from the top left door to their corresponding plate line. The finished goods for plate line 8 and 5 are able to flow easily to the finished goods storage located in the lower right hand corner with overflow into the soft-wall area.
Because there is a return conveyor for plate line 2 and 7, the finished goods end up next to the front-end operators. These finished goods must be transported through the length of the room to the finished good storage, which is located in the soft-wall cleanroom. The AES area in this layout is more in the corner than spread out along the exterior wall in the first layout. This allows for more space for walkways for operators and carts.

**Alternate Layout 3: Modified Vertical Layout**

![Diagram of Modified Vertical Layout]

*Figure 15: Modified Vertical Layout*
The positioning for these plate lines show some plate lines going in different directions than the proposed layout in alternate layout 2. Plate line 2 is flush against the wall. There is still plenty of space for the operator to move freely without any interference. This positioning also allows for the finished goods to come off the lines and move to the large finished goods storage. The positions for these plate lines allow for the finished goods to be moved from the lines and moved directly to the storage area located in the lower right area of the plate room. Access to and from the kitchen is either the door on the left side, so media receptacles can be easily transported to any plate line without having to travel along the length of the room.

**Methodology**

After all the layouts have been established, the best layout must be selected. A systematic analysis of each of the layouts helps determine the best or optimal layout for this facility. This quantitative analysis consists of defining evaluation metrics and then scoring each design based on how each well the layout complies with the metrics. In addition to these evaluation metrics

**Evaluate Alternatives**

**Evaluation Metrics**

The main way to evaluate alternative layouts is by designing metrics according to the needs of the plate room technicians. Once the metrics have been established, weights are assigned to each of the metrics where more important metrics are given more weight
and less important metrics are given less weight. Employee interviews and surveys are conducted to help understand the preferences and metrics for evaluation.

The evaluation of these layouts determined for the facility is broken into six metrics. The most important metric is the space needed for each function in the facility. This metric was given a 35% weight because the operators need the appropriate space around their work areas in order to move carts, sealers and media receptacles around them. The next metric is the width of the walkways, which was given a 25% weight because personnel and items must pass freely throughout the layout. Walkways must meet the required three feet minimum in addition to passing space for operators since many items (carts and reactors) may obscure the walkways. It is also preferable to keep the distance traveled for reactors to a minimum because the 400-liter reactors are notorious for scuffing and tearing up the floor. The third metric is the overall flow of the main plate lines and a 25% weigh has been given. It is essential that the flow of the products move smoothly throughout the plate room. The next 3 metrics all have to do with the proximity from the plate lines or work stations to kitchen doors, empty plates storage and the finished goods storage. These three metrics are each given a 5% weight. A summary of these metrics and their given weights can be found in the Appendix.

Now that the metrics and weights have been identified, the alternate layouts can now be evaluated. For each metric in each layout there is a score given out of 10. Depending on the score given and the weight of that metric, the best choice is selected from this layout. Each layout evaluation has a table with the score given for each metric and it’s reasoning.
### Horizontal Layout Evaluation

<table>
<thead>
<tr>
<th>Metric</th>
<th>Score</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space needed for operators</td>
<td>5</td>
<td>There is very little clearance between the left side of the room to the plate lines for operator space. There is approximately 2’-3’ of space from the wall to the plate lines (for lines 5, 7, and 8)</td>
</tr>
<tr>
<td>Walk-ways</td>
<td>7</td>
<td>There is enough space to move reactors between the walkways. Although in the 2’-3’ walkways mentioned above some of the larger reactors will not fit.</td>
</tr>
<tr>
<td>Flow</td>
<td>3</td>
<td>Because there was little room around the plate rooms, it is apparent that the flow is often interrupted.</td>
</tr>
<tr>
<td>Kitchen door proximity</td>
<td>10</td>
<td>All plate lines’ front-end operators are close to the kitchen doors.</td>
</tr>
<tr>
<td>Empty plate proximity</td>
<td>4</td>
<td>Plate line 8 and 2 have the best access to the empty plate carts, the others do not.</td>
</tr>
<tr>
<td>Finished goods proximity</td>
<td>3</td>
<td>Plate line 5 has the best access to this storage area. The other plate lines must pass by the narrow walkways in order to get to the finished goods storage.</td>
</tr>
</tbody>
</table>

### Vertical Layout Evaluation

<table>
<thead>
<tr>
<th>Metric</th>
<th>Score</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space needed for operators</td>
<td>10</td>
<td>This layout shows that there is plenty of room around each workstation.</td>
</tr>
<tr>
<td>Walk-ways</td>
<td>7</td>
<td>Most of the walkways are wide enough for the larger reactors however the walkway between the mobile HEPA and line 8 shows very little allowance for operators.</td>
</tr>
<tr>
<td>Flow</td>
<td>6</td>
<td>The flow of product coming into the plate room from the kitchen shows one point of entry but there is some cross traffic between the walkways.</td>
</tr>
<tr>
<td>Kitchen door proximity</td>
<td>5</td>
<td>Lines 5 and 7 have a good proximity to the kitchen doors but lines 2 and 8 do not.</td>
</tr>
<tr>
<td>Empty plate proximity</td>
<td>8</td>
<td>All of the plate lines have their front end operations near the storage for the empty plates</td>
</tr>
<tr>
<td>Finished goods proximity</td>
<td>5</td>
<td>Because line 2 and 7 have their finished goods returning to the frontend operator, the finished goods storage area is on the opposite of the room and the operator has a longer distance to travel.</td>
</tr>
</tbody>
</table>
Modified Vertical Layout Evaluation

<table>
<thead>
<tr>
<th>Metric</th>
<th>Score</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space needed for operators</td>
<td>10</td>
<td>Similarly to the second alternate layout, there is adequate space for all of the operators to move freely to perform their tasks and functions.</td>
</tr>
<tr>
<td>Walk-ways</td>
<td>10</td>
<td>In this layout, there is plenty of space for reactors, and operators can pass without bumping into any objects.</td>
</tr>
<tr>
<td>Flow</td>
<td>7</td>
<td>The flow shows two points of entry for the kitchen but all the plate lines show that the finished goods have a direct path to the finished goods storage.</td>
</tr>
<tr>
<td>Kitchen door proximity</td>
<td>5</td>
<td>The lines closest to the kitchen doors have the best proximity but the other ones do not because they are on the opposite side of the room.</td>
</tr>
<tr>
<td>Empty plate proximity</td>
<td>5</td>
<td>Only line 8 and line 5 have the best proximity for the empty plate lines. The other lines need to have this raw material move to where the frontend operators use them.</td>
</tr>
<tr>
<td>Finished goods proximity</td>
<td>8</td>
<td>All of the plate lines have the finished products flowing out in the same direction. There is a short distance between the lines and the finished goods storage area.</td>
</tr>
</tbody>
</table>

Results

After each layout has been properly evaluated, a comparison can be made to select the best layout. As mentioned before, each metric is assigned a weight. These weights are multiplied by the scores given and a total index is found. The highest index is selected as the best layout. The following is a multi-attribute analysis of three alternate layouts:
### Table 2: Evaluation Metric Analysis

<table>
<thead>
<tr>
<th>Metric</th>
<th>Weight</th>
<th>Horizontal Layout</th>
<th>Vertical Layout</th>
<th>Modified Vertical Layout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Needed</td>
<td>35%</td>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Walkways</td>
<td>25%</td>
<td>7</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Flow</td>
<td>25%</td>
<td>3</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Kitchen door proximity</td>
<td>5%</td>
<td>10</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Empty plates proximity</td>
<td>5%</td>
<td>4</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Finished goods proximity</td>
<td>5%</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Sum</td>
<td>100%</td>
<td>32</td>
<td>42</td>
<td>45</td>
</tr>
<tr>
<td>Score</td>
<td>10</td>
<td>4.4</td>
<td>7.65</td>
<td>8.65</td>
</tr>
</tbody>
</table>

**Select layout**

As the results indicate, the best layout is the modified vertical layout, which yields the highest score. After the manufacturing director agreed that alternate 3 was the best layout that met his criteria, he set up a meeting with the President, Jay Hardy to talk about this design and it's implementation. The layout design was approved. There was concern pertaining to the implementation of moving the largest plate line from one room to another. The maintenance group lead was also present in the meeting and confirmed that moving the plate line is feasible.

Because this layout has been selected, the cost justifications for this layout design can be made to determine the payback period. The cost is determined by the amount of overtime the maintenance department must commit to moving the different objects in the plate room. The cost of overtime for one employee is $24. There are 4 employees who work an hourly wage and the department lead is on a salary base. The total cost of overtime of
three employees is $72 per hour. According to the company's planning of the layout implementation, there is an estimated 30 hours of overtime. It is estimated that this work will be completed over the course of three months with overtime spent on the weekends for the maintenance group. There also an estimated $1000 allocated for contract work. In total it would cost about $3880.
**Implementation and Cost Justification**

With the completion of this the selected layout, there is 100% visibility of all plate production. In addition to this, the company would save approximately $655 per year due to the transportation time. The savings was computed by finding the time operators wasted traveling from the kitchen to the south wall production room. This transportation time is taken from the time it took 2 operators to move the large reactors a distance of 304 feet to and from the south wall production room. Also the packager must move the finished goods
to the walk-in refrigerator, which is a distance of 76 feet. In total, the operators and packager will walk a total of 680 feet for one production run. It is assumed that there is 5 runs/day and a total of 254 production days in a year. If the operators are walking at a 3 miles per hour pace and they are paid at a rate of $24 an hour then there is a total savings of $1296/year. After the implementation, the distance a reactor must travel is reduced by 77% because the reactor would only travel a distance of approximately 34 feet. Hardy will see a savings of approximately $655 per year and they will see the payback in just under 3 years. The payback calculation is as follows:

\[
\frac{680 \text{ feet}}{\text{run}} \times \frac{5 \text{ runs}}{\text{day}} \times \frac{254 \text{ days}}{\text{year}} \times \frac{1 \text{ mile}}{5280 \text{ feet}} \times \frac{1 \text{ hour}}{3 \text{ miles}} = \frac{54 \text{ hours}}{\text{year}}
\]

\[
\frac{54 \text{ hours}}{\text{year}} \times \frac{24 \text{ dollars}}{\text{hour}} = \frac{1296 \text{ dollars}}{\text{year}}
\]

\[
\frac{1296 \text{ dollars}}{\text{year}} \div 3880 \text{ dollars/year} = 2.99 \text{ years or 3 years} = \text{payback}
\]

**Conclusion**

The company's goal of consolidating all of the plate production into one room has been met. This implementation allows for better visibility of the plate production, transportation time and costs are decreased and better communication between the managers and all plate line technicians result from the layout design. By moving line 8 into the plate room, a perfectly good cleanroom has been freed and plenty of space is available for expansion or consolidation of the tube department.

Although the company must incur a cost of almost $7000, it is a small price to pay with all things considered. In addition to the goal being met, employee satisfaction is
increased because managers will be able to send them to breaks on time and there is more transparency between the management and the technicians. Even though this change does not directly affect the end product or Hardy’s customers it does improve morale of its employees, which is embedded in the company’s core values.
Figure 17: Previous layout in plate room only
Figure 18: Production Flow in Hardy Facility for the plate room only

Table 3: Relationship chart of departments

<table>
<thead>
<tr>
<th>From/To</th>
<th>Line 2</th>
<th>Line 5</th>
<th>Line 7</th>
<th>Line 8</th>
<th>AES</th>
<th>Bench</th>
<th>AnaeroGro</th>
<th>QC box</th>
<th>Comp</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 2</td>
<td>--</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Line 5</td>
<td>U</td>
<td>--</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Line 7</td>
<td>U</td>
<td>U</td>
<td>--</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Line 8</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>--</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>AES</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>--</td>
<td>U</td>
<td>U</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Bench</td>
<td>U</td>
<td>U</td>
<td>O</td>
<td>U</td>
<td>U</td>
<td>--</td>
<td>U</td>
<td>O</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>AnaeroGro</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>--</td>
<td>O</td>
<td>U</td>
<td>O</td>
</tr>
<tr>
<td>QC Box</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>O</td>
<td>--</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Computer</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>U</td>
<td>U</td>
<td>O</td>
<td>--</td>
<td>U</td>
</tr>
<tr>
<td>Storage</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>U</td>
<td>O</td>
<td>U</td>
<td>U</td>
<td>--</td>
</tr>
</tbody>
</table>

Relationship Diagram Weights
A Absolutely Necessary
E Especially Important
I Important
O Ordinary closeness
U Unimportant
X Undesirable
Table 4: Total space requirements in plate room

<table>
<thead>
<tr>
<th>Department</th>
<th>Total Space requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 2</td>
<td>119 ft²</td>
</tr>
<tr>
<td>Line 5</td>
<td>89.25 ft²</td>
</tr>
<tr>
<td>Line 7</td>
<td>112.75 ft²</td>
</tr>
<tr>
<td>Line 8</td>
<td>222 ft²</td>
</tr>
<tr>
<td>AES</td>
<td>129.25 ft²</td>
</tr>
<tr>
<td>Clean Bench</td>
<td>25.5 ft²</td>
</tr>
<tr>
<td>AnaeroGro Sealer</td>
<td>20 ft²</td>
</tr>
<tr>
<td>Computer Stations (2)</td>
<td>2 ft² each</td>
</tr>
<tr>
<td>RM Storage</td>
<td>30 ft²</td>
</tr>
<tr>
<td>FG Storage</td>
<td>32 ft²</td>
</tr>
<tr>
<td>Vestibule</td>
<td>16 ft²</td>
</tr>
<tr>
<td>Soft-wall corridor (outside room)</td>
<td>338 ft²</td>
</tr>
<tr>
<td>Total space needed without Soft-wall</td>
<td>799.75 ft²</td>
</tr>
<tr>
<td>Total space needed with Soft-wall</td>
<td>1137.75 ft²</td>
</tr>
</tbody>
</table>

Table 5: Summary of Evaluation Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Needed</td>
<td>40%</td>
</tr>
<tr>
<td>Walkways</td>
<td>30%</td>
</tr>
<tr>
<td>Kitchen door proximity</td>
<td>10%</td>
</tr>
<tr>
<td>Empty plates proximity</td>
<td>10%</td>
</tr>
<tr>
<td>Finished goods proximity</td>
<td>10%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>
Bibliography


