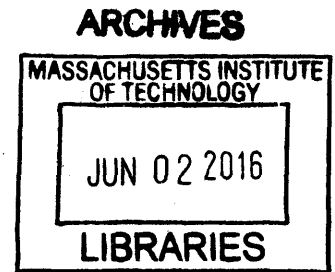


**Operations and Strategy Improvement:  
Form and Functionality Optimization of an  
Assembly System Design**

By  
Joseph M. Falvella



Bachelor of Science, Mechanical Engineering and Engineering Business  
University of Virginia, 2012

Submitted to the Department of Mechanical Engineering  
in Partial Fulfillment of the Requirements for the Degree of  
Master of Engineering in Manufacturing  
at the

**Massachusetts Institute of Technology**

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Submitted to the Department of Mechanical Engineering  
on January 21, 2014 in Partial Fulfillment of the  
Requirements for the Degree of Master of Engineering in Manufacturing

## **Abstract**

The purpose of this thesis is to show a systematic approach to identify bottlenecks and “pain points” in the operations of a manufacturing firm, to identify the root causes of such problems, and explore viable solutions.

Furthermore, the purpose of this thesis is to serve as a strategic tool for implementation of the proposed solutions. This thesis covers the entire mapping of the manufacturer’s current facility, the physical layout as well as the material and process flow, and includes a proposal for a new streamlined layout that optimizes floor space, reduces work in progress, and ultimately increases efficiency in the entire process.

This proposal is done with the consideration that said manufacturing facility is looking to acquire new machinery and expand operations. Covered in this thesis is not just the final proposal for a new layout, but a detailed plan with milestones explaining the necessary steps it would take to convert the factory, without interrupting current production.

Thesis Supervisor: Stanley Gershwin

Title: Senior Research Scientist, Department of Mechanical Engineering

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These two professors make MIT what it is.

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## **1. Introduction**

This thesis was prepared in partial fulfillment of the requirements for the degree of Master of Engineering in Manufacturing at the Massachusetts Institute of Technology. The thesis research took part over the Independent Activity Period (January term), one day a week during the Spring 2013 semester, and full time over the summer term from May 20, 2013 through August 9, 2013. Although three students from MIT were present at the assigned servo-drive manufacturing company to help solve an industry problem, our analysis as a group identified several areas to address. Therefore, each one of us chose an individual problem area to focus on in order to have a greater impact for the company. As required by the signed Non-Disclosure agreements, the company, its products, assemblies, subassemblies, and other relevant information will remain anonymous or will be renamed.

### **1.1 Company Background**

The company manufactures AC drives, positioning control, belt, servo, PLCs and peripherals, automation and control software, motor control devices, conveyor controls, and mechanical drive components. Their products meet NEMA standards (National Electronics Manufacturers Association). The current factory is roughly 50,000 square feet, has a fully staffed first shift, a partially staffed second shift (about 20 percent capacity), and no third shift operations. On average, the current manufacturing process has a throughput of about 3000 drives per week. The company is experiencing high demand due to implementation of automation procedures across many industry sectors, and also has plans to introduce its next generation of products within 24 months.

## **1.2 Motivation**

The motivation of this project is to improve material flow during the manufacturing process by implementing optimization techniques. The current set up of equipment was analyzed, a blueprint was drawn up, and every part of the process was mapped in order to understand how each subcomponent of the process interacted with the main process. The final result is a new floor plan layout design that increases throughput, makes efficient use of the manpower currently at the company, reduces bottlenecking in the process, eliminates non-essential buffers, and improves the quality of the product. In addition, the objective is to optimize the current footprint of the equipment on the factory floor. This will make room for additional assembly lines that will produce the next generation of product. The goal is to have this fit in the current facility, and save the company from having to construct another building.

## **1.3 Organization of Thesis**

Chapter 2 of this thesis identifies the problem statement, the goal of the intended outcome, and the scope that this project encompasses – both in the recommendation of a plan of action, and the implementation of a plan of action. Introduction of a high level overview of the methodology used to analyze the current system will be covered in Chapter 3. The content of the Chapter 4 covers tools that will be used to analyze the current process and material flow. Chapter 5 describes the current layout of the factory and all of its sub-systems. Chapter 6 uses the analysis in the previous chapter to configure a new layout that reduces bottlenecks in the system, increases throughput, and optimizes the current floor space of the factory while making room for the future equipment needed for its next generation of product. A 12~15 month proposal for full conversion, with milestones and detailed transition points is explained in Chapter 7.

## **2. Problem Statement**

In order to define the problem statement, our group (three MIT students) spent the first few weeks understanding the entire process of the company, asking open ended questions to all levels of employees, identifying problems in each process area, determining relationships between each area, and recording all of the input. We then used hypothesis-driven problem identification to prioritize the potential project areas and made decisions on which projects to pursue.

### **2.1 Input**

We spoke to operators in different areas on the floor, as well as managers, and asked questions about why procedures were performed a certain way, what they would do differently, what they perceive as the biggest problems in the current system, etc. In each area, we received different answers with respect to what needs the most improvement. We then used all of this information to start identifying root causes of problems in the current system.

#### **2.1.1 Board Test Area**

The electronic board test area has poorly written test procedure documentation and there is a lot of confusion about what test figures are current or obsolete. This is not just a time factor, it is a safety factor. Wrong documentation can lead to safety issues or product failure problems further downstream in the manufacturing process. As for the test fixtures, they lack a robust, well thought out design; this leads to many failures and repairs. The combination of poorly written or obsolete test documentation, combined with test fixtures that consistently fail, results in repeat work, unreliable test data, and a bottleneck in the system.

### **2.1.2 Warehouse**

Input from employees in the warehouse area revealed problems such as not enough space to properly organize and store inventory and poor documentation indicating whether items stayed in the rear warehouse or if some items were to be brought to the bulk bins on the factory floor near the assembly lines. Additional input from the warehouse employees found that they would sometimes run out of rolling racks to put the kits of supplies onto. As a result, employees either have to wait for empty racks to become available, or they over-pack an existing rack to keep up with scheduling. The latter results in a lot of “non-value” added work due to the amount of time it takes to sort through the cart. Overloading the carts also creates a safety hazard as carts are stacked too high for some of operators to reach, and the heavier boxes are often not stable.

### **2.1.3 Manufacturing**

A general overview of the manufacturing problems identified the fact that there have been a lot of quick fixes over the last decade and the entire process was due for an overhaul. Some of the input that we heard was that there was a major problem with documentation, ownership of the documentation changes, and with engineering in general. Many of the bills of material (BOM) were wrong or not updated. Major concerns with the actual manufacturing were the amount of handling, or non-value added work in the current process, as well as work-in-progress buffers between each manufacturing area. Other smaller problems were the occasional product part that was not at the factory in time and pushed the manufacturing schedule back.

### **2.1.4 Assembly**

We spoke with many of the people on the assembly lines, especially in the drive assembly area and found that a lot of time was wasted due to unpacking the components from boxes and searching for the right components on the cart. Time trials were conducted to verify this, and the result was that up to twenty percent of

the overall assembly time was spent as non-value added work due to opening cardboard boxes, searching for components on the rack, rearranging the rack to find parts, breaking down the cardboard boxes to dispose of them.

### **2.1.5 Engineering**

Our analysis as a team revealed that there was a lack of engineering change notice (ECN) process, poor document revision control, and poor or no computer aided design (CAD) revision control. In addition, there was a lack of accurate engineering data, and a gross lack of accurate engineering bill of materials (BOM) existing on the floor at point of test and assembly. This resulted in a lot of confusion and made problem solving extremely difficult. It was also apparent that the firm was understaffed in the engineering department overall and needed at least one person strictly dedicated to engineering documentation.

### **2.1.6 Supply Chain**

The order fulfillment policy for servo-drives is based on the quantities of drives ordered. There are four major categories of drives; A, B, C, and D. The A and B categories are stocked in-house and are manufactured in bulk; the forecasting and fulfillment process for these is well understood and is fairly consistent. The C and D types are not in a constant demand and it is often difficult to schedule the parts needed for manufacturing.

The allocation of the A, B, C, and D items has not been done for over a year, since the person in charge of it left. It is highly likely that the allocation has remained accurate over this time period.

## 2.2 Root Cause Problem Analysis

Figure 1 is a diagram of the analysis that our group used to determine three major problem areas that each one of use would work on as an individual thesis. The text in this chapter gives a brief description of each segment.

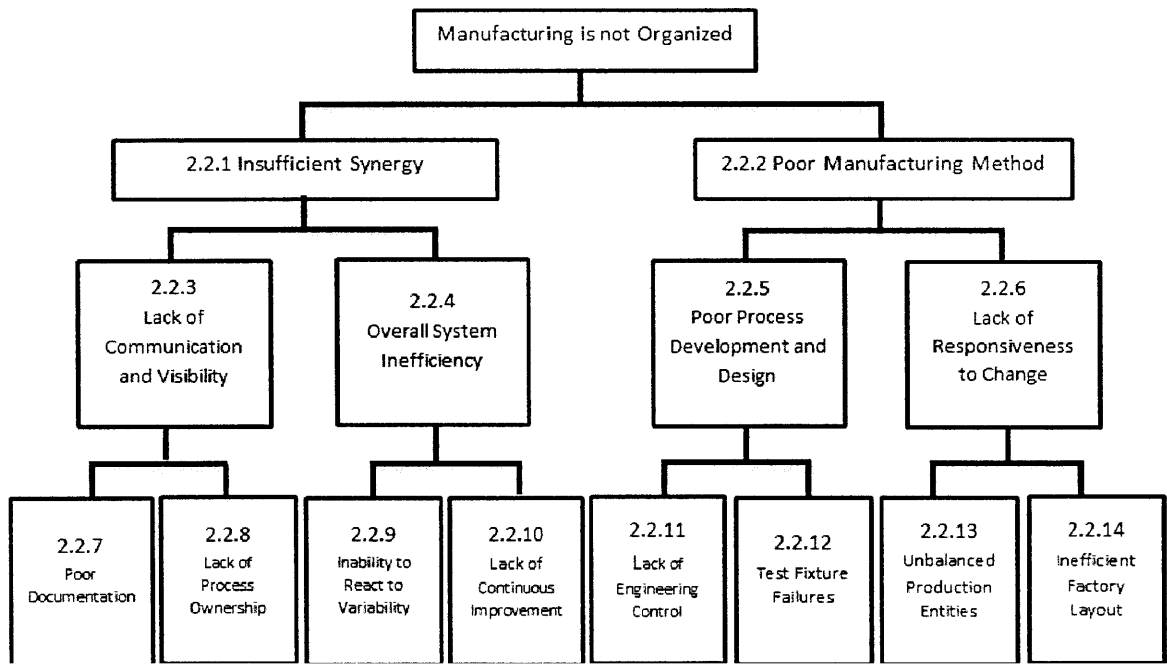


Figure 1: Root Cause Problem Identification

### 2.2.1 Insufficient Synergy

Planning and communication between departments was currently not in line with existing capabilities. There was a lack of understanding of resources and customer expectations, inefficiencies in balancing of orders, forecasting, manufacturing, and a lack of collaboration between departments. Customer service representatives do not have first-hand information on the shop floor loadings; this means orders get booked based on a default time scale and not on the utilization of the shop floor resources (i.e. the customer commitments are made without accounting for the resource utilization in the shop)

### **2.2.2 Poor Manufacturing Methods**

The manufacturing process on the shop floor is not efficiently designed. The build sheets are not updated and contained obsolete information, there is poor documentation on work performed, and there is a lack of visibility and communication between build areas. In addition, the processes that are used for large orders are applied to small orders, and this may not lead to optimal performance. Finally, the manpower planning schedule is not aligned with manufacturing demands and the current set up does not allow for a flexible manufacturing system; the company is not able to quickly react to variability in the demand.

### **2.2.3 Lack of Communication and Visibility**

We found a lack of communication between several areas of the plant such as the sales department and the manufacturing department, the supply chain department and the production scheduling department, and specifically personnel on the manufacturing floor. We observed that communication between the manufacturing area and the engineering department had many obstacles so information was often not communicated from one party to the other. In general, we found that many areas in the company simply did not have open lines of communication with other departments. This has a negative impact on the entire manufacturing process.

### **2.2.4 Overall System Inefficiency**

Falling under the subcategory of synergy is overall system inefficiency. While a portion of this is due to the communication problems previously mentioned, there are other contributors to system inefficiencies that are present in the company. Much of the manufacturing work is hand assembly and performed at work stations that are poorly designed for efficiency. Furthermore, much of the assembly process could be contracted out or automated. Current technologies provide a more efficient way of manufacturing and assembly of some of the components currently assembled at the

plant. This factory has cross-trained most of its workers and as some of the subassembly work is replaced by automation, the displaced workers could transfer over to the main assembly line where the company tends to be shorthanded.

### **2.2.5 Poor Process Development and Design**

The process development and design component of this company is based on a lot of its legacy product, but the company is in the process of moving toward a next generation of product that has a lot more integration in the components and the assembly portion. However, the current process of manufacturing and assembly is poorly constructed and many quick fixes have been applied over a long period of time. The inadequacies of the current method have propagated into a multitude of bottlenecks in the current process. A new direction and method of addressing problems with continuous feedback and improvement should be put in place.

### **2.2.6 Lack of Responsiveness to Change**

As a result of poor process development and design strategies in place, plus the existing manufacturing inefficiencies, the current system is unable to react to variability quickly. This applies to short term change, such as spikes and rushes in orders, the ability to react to shortages in supply chain deliveries, but also long term changes such as adopting new procedures, and technologies, that would greatly benefit the company.

### **2.2.7 Poor Documentation**

Documentation of test procedures for board testing, subassembly testing, and final drive assembly were outdated and in scattered stages of upgrade. Many of the changes that should have been made were never processed completely (some pre-release documents are in place), and some problems were never addressed at all. As a result, much of the work force relies on tacit knowledge with respect to testing procedures that have not been updated, but the correct way is often unknown. This



is a large concern for not just efficiency, but overall safety of the workforce, especially in the testing areas or other procedures where electrical power is in use.

### **2.2.8 Lack of Process Ownership**

Many of the processes and procedures appeared to have been started but follow up on these often seemed to fall short. The writing and documentation of test procedures is an example as there seemed to be no particular person in charge of following up, revising, and implementing changes to said documents. Furthermore, there were other projects that seemed to be initiated and approved by a group, but appeared to either be stalled or put on the side; possibly as a result of a lack of overall process ownership. This statement is merely speculation, as financial constraints are often a reason for not following through, but in the input that our group gathered; it appeared to lean more towards a lack of ownership.

### **2.2.9 Inability to React to Variability**

The current framework of the company does not lend itself the ability to react to variability as good as it could be able to. As mentioned earlier, portions of the company are in silos and better communication and planning would alleviate some of these constraints. Another issue that came to light was the way in which customer orders were processed into orders and then submitted to the factory floor. There appears to be four main categories of products (A, B, C, D). Some of the minor products or legacy products (C and D) cause bottlenecks when introduced as a rush order part. Part of this reason is because these products are not built often and the hardware and materials for these is not always on hand. This is information that we gathered from managers and employees.

Another observation was that although much of the labor was cross trained, it appeared that the company was understaffed. More employees on the work floor would allow greater flexibility and a faster response time. Currently, the operating procedure moves people around from different station and I believe that the

customer demands for the product warrant a few more laborers. In addition, the company was greatly understaffed in the areas of manufacturing engineers and mechanical engineers. The majority of the engineers on hand were electrical engineers. More engineering perspective would aid in robust design and process management.

### **2.2.10 Lack of Continuous Improvement**

The current process in the factory, while functioning and profitable, does not have continuous improvement methods in place. As it stands, many of the fixes implemented over time have been quick fixes and did not necessarily identify the root cause. Even worse, some of the “fixes” caused other problems in the process. A continuous improvement strategy, where the process is continuously monitored and solutions are decided as a group, implemented and reviewed, and refined as needed would resolve some of the current problems. As well, this process has to be in the immediate control of those directly involved. Take for example the final assembly line portion of the manufacturing process; continuous improvement changes in that process should be identified, and resolved by a group consisting of the line manager, the employees who do the assembly, and final approval by the manufacturing engineer. Implementing this into the process would also allow the company to react more quickly to variations and changes in the work orders

### **2.2.11 Lack of Engineering Control**

Currently, the engineering department seems to be understaffed for the demands of this factory. If they are not understaffed then they are not properly aligned. One major concern is that the entire engineering department is on a different floor level than the actual manufacturing facility. This scenario alone causes a silo and a lack of oversight. Engineering, especially the portions directly involved with testing, fixture design, documentation, and anything else directly related to procedures on the floor should be right there on the factory floor.

### **2.2.12 Test Fixture Failures**

Test fixtures were one of the major, if not the biggest bottleneck in the entire system. The test fixtures were poorly designed, they were not easy to use, they were not easy to troubleshoot and repair, and there were no duplicates in case one fixture was down for repair. Furthermore, the fixtures flexed the control board when clamped down for testing, they did not have the capability to be adjusted for different scenarios, and the plastic clamps that were made in house via a fused deposition modeling (FDM) printer did not meet electrostatic discharge (ESD) code.

### **2.2.13 Unbalanced Production Entities**

There are several different product lines produced in the factory and there are several buffers on the floor, especially stationary shelves that hold up to several hundred of the product between stages. There were machines that were known to go down more often than others - lower mean time to fail (MTTF). One example is the wave-solder machines. There are buffers before and after the machine. The buffer before was for when the machine was down and work upstream piled up. The buffer after was for when second shift would run the wave solder to catch up and finished boards would be placed in the post-buffer for the next day's first shift station immediately downstream from the wave-solder machine.

### **2.2.14 Inefficient Plant Layout**

The current plant layout is not streamlined and has a lot of unnecessary redundancies. Manufacturing processes need redundancies as fail safes to ensure that a product meets and exceeds all requirements and for quality control. However, there are a lot of redundancies in the current process that do not have an impact and should be eliminated in order to increase efficiency and throughput. The products travel a much greater distance throughout the factory than needed and the overall flow of materials is scattered. Other areas of the plant hinder safety, visibility, and process of material flow. The future state of the company is a one piece flow for

manufacturing so the entire plant has to be redesigned in order to accommodate this future state

### **2.3 Results of Root Cause Problem Analysis**

The analysis of the system revealed the following:

1. The current board test fixtures and documentation are poorly designed and cause bottlenecks in the manufacturing process
2. The current layout of the manufacturing facility has a lot of waste, is poorly organized, and is not optimal for streamlined performance
3. The company is in the phase of introducing a new product line and this is an opportunity to redefine their process development phase. An analysis and simulation of the manufacturing line for this new product addresses this.

As a result, my teammates and I each chose one of the three areas listed above. My thesis will address result 2: the current layout of the factory and making improvements to achieve optimal use of the resources at hand; both optimizing the throughput of the current production lines and streamlining in order to open up a large amount of floor space for the next generation of products assembly line. The analysis of board test fixture documentation as well as a redesign of the fixture itself will be addressed by another member of the team's thesis [1]. The impact and demand analysis of the next generation of product line will be address by the last team mate thesis [2].

### **2.4 Problem Statement**

I broke down my problem statement into two sections; Problem Statement I & II. Problem Statement I had to be resolved before problem statement II could be addresses.

### **2.4.1 Problem Statement I**

The current design and line balance of the assembly lines needs improvement to meet production schedule demands.

- Question: What improvements and changes can be made to an assembly line to improve efficiency and meet demands, and what other servo drives should be added?
- Hypothesis: A Kaizen Blitz event, to be performed over the course of three days, will identify inefficiencies, redundancies, and non-value added work procedures.

### **2.4.2 Problem Statement II**

The current layout of the manufacturing facility is not conducive to an optimized flow of materials, efficient throughput, and use of resources.

- Question: Given the current square footage of the manufacturing facility, what is the optimal layout to improve manufacturing throughput, increase productivity, and what resources should be used to implement these changes? What are the different layout configurations that are possible, what are the impacts of these configurations, and how much can we streamline the configuration without having a negative impact on production?
- Hypothesis: Improving the current layout will have a positive impact on the current manufacturing process as well and the future state of the company.

## **3. Literature Review**

To start the process of a new design layout, I researched many resources. Aside from input from people directly related to the process, I researched many types of methods utilized in optimizing and managing process controls such as Kaizen, Lean Manufacturing, Six Sigma, and Change Management to name a few.

### **3.1 Kaizen**

Kaizen is a management concept of Japanese origin that focuses on incremental, gradual, and continuous improvement. Kaizen literally translates to: Change (kai) to become good (zen). The philosophy of Kaizen is the foundation for other management concepts such as Total Quality Management (TQM), labor relations, and other types of group based organization improvement activities. The key elements of Kaizen are communication, involvement of employees, willingness to change, attention to quality, and effort. Kaizen consist of 5 founding elements

- Teamwork
- Personal discipline
- Improved morale
- Quality circles
- Suggestions for improvement

Stemming from these founding elements are the three key factors of Kaizen

- Elimination of waste and inefficiencies
- Standardization

Kaizen - incremental and continuous change process - requires a commitment and a collective culture focused on sustaining that change. Kaizen is extremely people oriented, easy to implement, but requires long term commitment [3].

### **3.2 Lean Manufacturing**

Lean manufacturing essentially focuses on reduction of waste in a system and a methodology of continuous improvement. The overall goal is to have a smooth flow, or balance, in the system thus reducing bottle necks and starvation points, and at the same time minimizing non value added work. This form of methodology is typically in place in large scale automotive assembly plants as well as may other large scale manufacturing sectors. "Lean is the relentless pursuit of the elimination of waste" [3].

Implementing a Lean approach should reduce the amount of work in progress (WIP), and the cycle times should decrease as a result of eliminating non-value added work in the manufacturing and assembly process (in our application). Lean can be applied to many things, but the concept was introduced by the Toyota Automotive company in the late twentieth century. Their approach is now championed by many companies and variations of it are implemented into current systems. The core components of a Lean Manufacturing approach are: reduction of set up and break down times, the ability for flexibility, inventory management, work station design, and Kaizen – mentioned in the previous section.

The reduction of set-up and break-down times adds efficiency in the overall process, especially when a line, or process, needs to have flexibility. If an assembly line, for example, has large and small batches of several different variations of a product, and the demand is such that those products cannot be held off and grouped, there could be a substantial amount of time used to break down tooling, components, and jigs for one model of a product, and then time spent on setting up those same components for the next product. Reducing the amount of time needed is crucial to reducing and eliminating WIP, reducing bottlenecks, and increasing the cycle time; not to mention increasing overall profits as well.

Increasing the ability for flexibility not only applies to having assembly lines that are able to accommodate variation in parts or products to be manufactures and assembled in a single line in order to streamline a process and optimize resources. Flexibility also applies to the workforce. Cross training employees has the same impact as adding flexibility to the production capabilities in a certain assembly line. It all falls under the idea of optimizing resources. One line is a lot more optimal if it has the ability to handle different products and the workers are cross trained to adapt to these variations, as well as any number of other variations.

Inventory management is essential. Its goal is to reduce the amount of WIP and manage bottlenecks and starvation points in the system. By balancing the work

stations in the process, and attempting to reach the goal of one piece flow, or at least “small batch” flow, problems or failures in a part, or process are detected earlier in the system, corrected earlier in the system, and there is a savings of time and money with respect to reworking parts.

Take for example a buffer that is holding 20 to 30 units of a product that are being assembled upstream, and consider that there is a test station after said buffer that tests and inspects the finished goods. If there is suddenly a consistently bad component being installed on this product, the testing station realizes it, but it realizes it after thirty more of these products has already been built. In addition, to maintain process flow, it is more conducive to take that entire batch and rework it somewhere else because they have to be broken down and rebuilt. If it were a one piece flow, the bad component would be recognized almost immediately at the next station. Therefore there would only be one or two products that had to be pulled and reworked. In addition, the bad component or whatever actual problem may arise can be resolved quickly. The failed product can easily be reworked right in the assembly line as there would only be one or two, and the negative impact on the throughput of the entire assembly process would be extremely minimal. In fact, this approach actually increases the overall throughput because the problems would be caught extremely early and the amount of rework would be minimized.



### 3.3 DMAIC

This project involves the optimizations of an existing process; the DMAIC methodology (Define, Measure, Analyze, Improve, and Control) will be utilized [3].

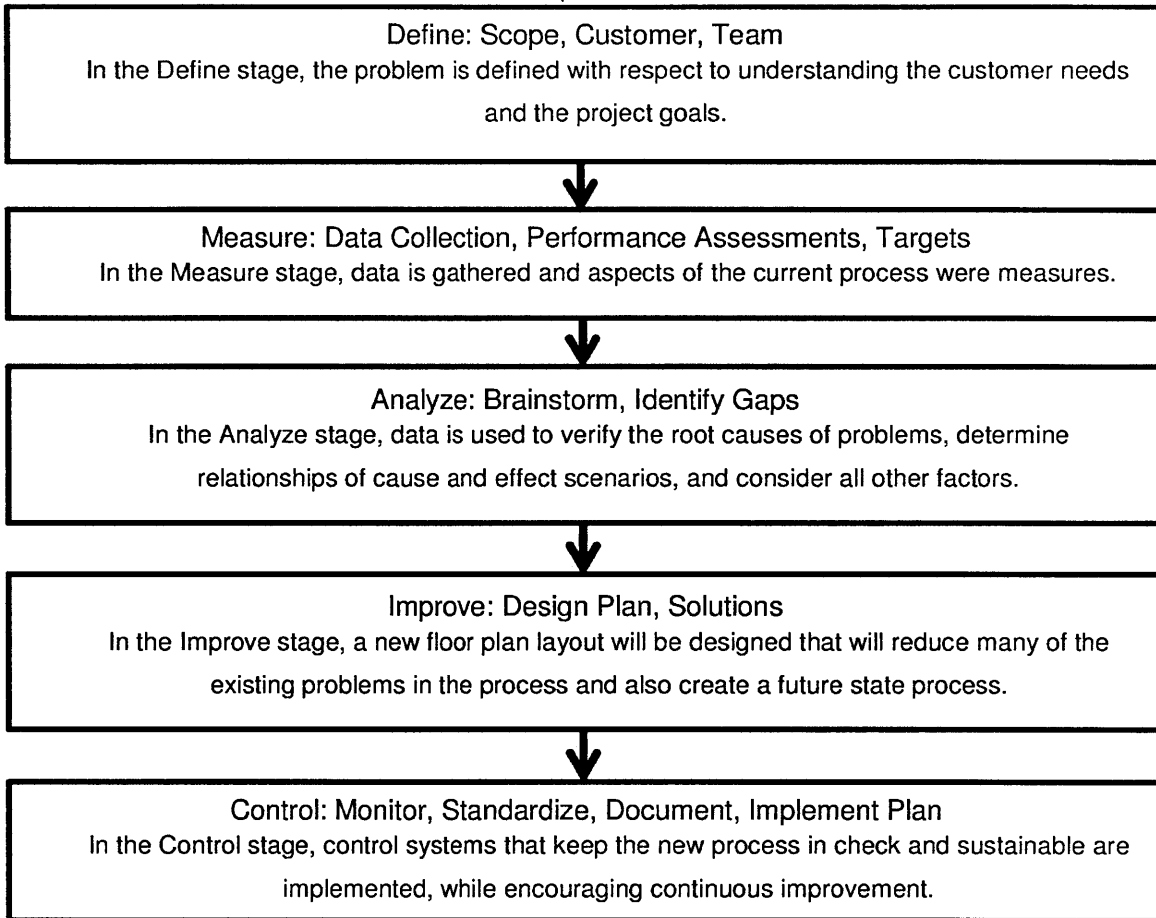


Figure 2: DMAIC Steps

The essence of this process is to

1. Know the customers' expectations
2. Understand how your process works
3. Know the sources and variations in the process
4. Eliminate or reduce the source of variation in the process
5. Verify that the changes made are successful on an ongoing basis.

In order for this process to be successful, there has to be “buy-in” from all levels (including upper management), training, and support. It starts at the top of the organization [3].

### **3.4 Agile Manufacturing**

Agile manufacturing is a term used to indicate the use of the principles of lean production on a broader scale. The principle behind agile manufacturing is ensuring flexibility (agility) into the manufacturing enterprise so that it can quickly respond to changes in product variety and customer demand variations [5]. Agile manufacturing focuses on flexible machines, assembly benches and or lines, and even modular designs in the product itself.

### **3.5 Change Management**

Change management is a structured approach used to transition and organization to a future state and refers to a project management process where changes to a project are introduced and improved, and when followed, helps to ensure smooth transition and lasting benefits. Because business environments change so rapidly, an organization must learn how to adapt and change quickly in order to be successful. Organization change, effectively implemented by change management, affects the entire company and every department.

“Four major factors should be considered when determining what innovations or techniques should be adopted” [8].

1. Levels, goals, and strategies
2. What type of measurement system
3. Sequence of steps
4. Implementation and organizational change

The critical aspect is a company's ability to win the buy-in of their organization's employees on the change. Effectively managing organizational change is a four-step process:

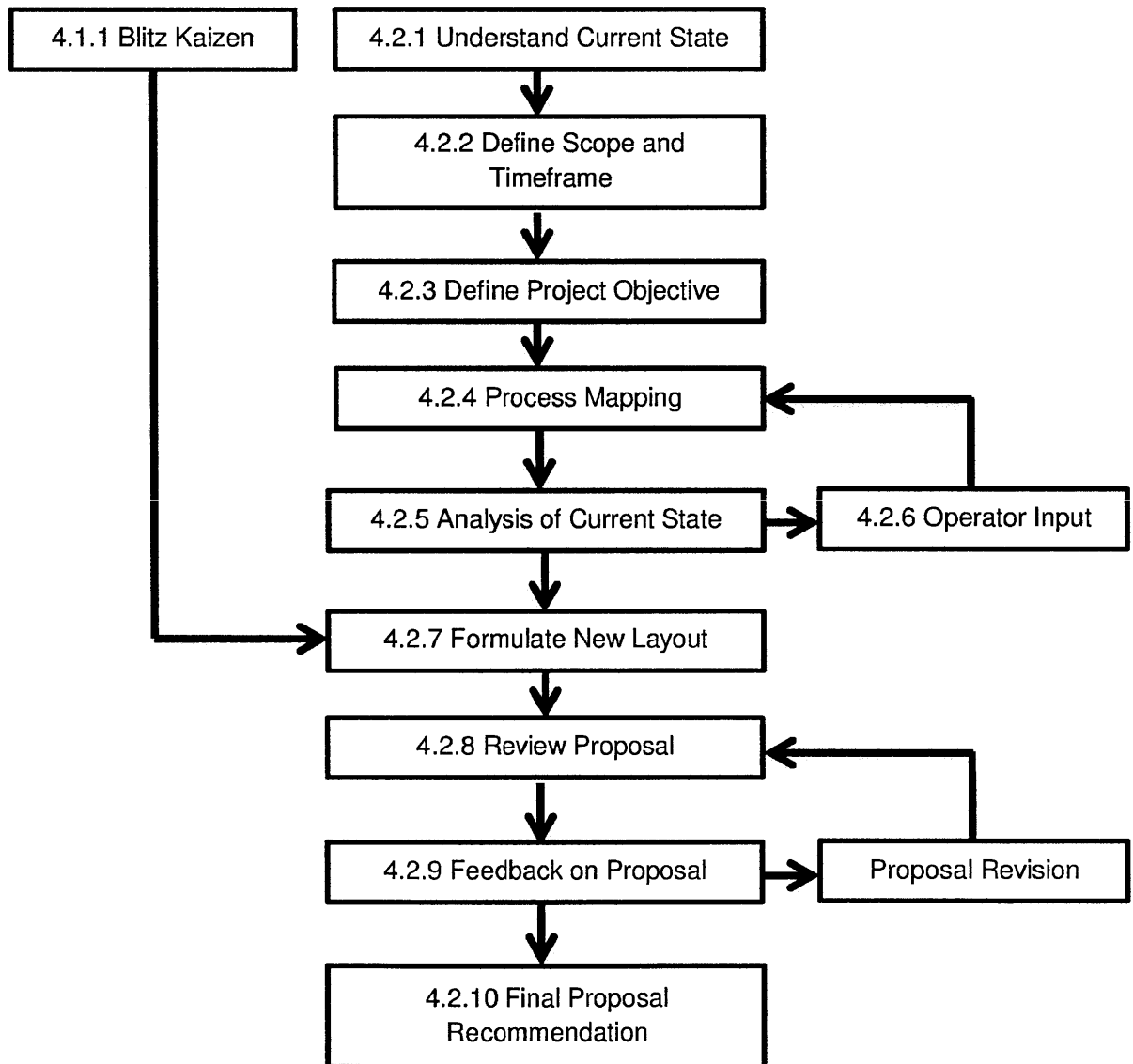
1. Recognizing the changes in the broader business environment.
2. Developing the necessary adjustments for their company's needs.
3. Training their employees on the appropriate changes.
4. Winning the support of the employees with the persuasiveness of the appropriate adjustments.

“Organizational Change Management should align the groups' expectations, communicates, integrates teams and manages people training. It uses performance metrics, such as operational efficiency, leadership commitment, communication effectiveness, and the perceived need for change to design sustainable strategies, in order to avoid change failures or resolve troubled change project.

#### **4. Methodology**

In order to understand the current manufacturing process system, a methodology flowchart is devised that would apply to redesigning a single assembly line in order to improve its physical layout and ability to operate efficiently. Then, that same methodology is applied to the larger project of improved productivity and efficiency for the entire factory.

The flowchart is shown below, and followed by descriptions of each step. The flowchart has two points to start at. 4.1.1. (Blitz Kaizen) was used for an intense focus on one specific area of the entire process. This was used for the single assembly line. The other starting point in the flowchart is the main components of a Kaizen event, but streamlined to apply to the very large-scale project of the entire factory.



Methodology Flow Chart

## **4.1 Addressing Problem Statement I – Methodology**

A Blitz Kaizen event was performed focusing on one assembly line in order to identify problems and areas that need improvement. In doing this, we will be able to set up this line as a model line that the remaining lines should look like.

### **4.1.1 Blitz Kaizen**

A Kaizen Blitz Event is a three day, intensive look at one portion of the system that involves participants from every tier of that process; operators, line managers, manufacturing managers, and quality control managers. The process of this event will map out the process from the end of the line back to the beginning of the line, and will address potential problem areas that range from safety, non-value added work, inefficient placement of tools and components, etc. As a group, we will then brainstorm solutions, agree on a plan of action, and implement with the understanding that continuous improvements and minor adjustments can be made in the system by the stakeholders as needed.

## **4.2 Addressing Problem Statement II – Methodology**

The second portion addressed the physical layout and increased productivity on the entire factory floor. This included the manufacturing process from the beginning to the end, and also accounted for the subassembly areas, and the materials that supply each area.

### **4.2.1 Understanding the Current State**

In order to understand the current state of the company's manufacturing process, I determined that I had to walk through the actual manufacturing process from start to finish in order to understand the process and material flow, and to understand the physical constraints of both the plant and the actual tools and machinery currently in place.

#### **4.2.2 Define Scope and Timeframe**

The scope of the project was to optimize the current factory floor configuration for maximum throughput and efficiency, while making room for the introduction of the next generation product in the near future (12-15 months). While the improvement process was a continuous one, I kept in mind that my final proposal would be handed off to management and implemented over the next 12 months.

#### **4.2.3 Define Project Objective**

The objective of this project was to optimize the form and functionality of the company's manufacturing process and result in maximum and efficient productivity in their current facility. Alongside the physical transformation of the plant were two other important transformations; the culture of the work force and employees at all levels had to be impacted in a positive way, and the workplace-safety of all employees was not to be compromised.

#### **4.2.4 Process Mapping**

To capture the current state of the company's facility, a map of the process chain had to be constructed. "Analogous to mapping DNA on the human genome, understanding and redesigning companies' capabilities chain also begins with a map, one which identifies the organizations or entities involved in the activity or subsystem that they provide, the capabilities that they bring to the value chain proposition, and the technical contribution each makes to the to the companies final product" [4].

The entire manufacturing process and material flow chain was mapped from the end of the line where finished goods are packing and shipped, all the way back to the beginning of the process where materials are brought out from the rear warehouse.

“In order to design , operate, or improve an assembly process, we need to visualize it on paper, bulletin boards, or computer screens in a variety of ways, keep these documents in sync with shop floor reality, and maintain revision histories” [5]. There are two main purposes for these renditions:

1. Communication. They provide implementation teams with a means of sharing information and expressing and reviewing design options.
2. Analysis. By highlighting some of the aspects of the process and finding out characteristics that we did not already know.

#### **4.2.5 Analysis of Current State**

After the process stream and material flow paths were mapped, I analyzed the redundancies and areas where there were bottlenecks and large buffers. In an attempt to reach a state that closely resembled one-piece-flow, I also had to find the root causes of why these problems were occurring.

#### **4.2.6 Operator Input**

Another crucial part of analyzing the current state of the manufacturing facility was gaining input from the assemblers and operators. This input was extremely important because a key component in designing a successful layout, and productive manufacturing facility, is being aware of what the operators and assemblers actually do and do not need to be efficient.

#### **4.2.7 Formulate New Layout**

Formulating new design layouts posed several hurdles because there were many constraints. The most important constraint was that the implementing the new design had to be a smooth transition and not interrupt existing production demands. Also, adding flexibility in the assembly process lines was a key element in order to accommodate variability in product demand on a weekly basis. The operators, assemblers, line managers, and the manufacturing managers were all involved in

group meetings where we identified problem areas and brainstormed ideas for solutions. Assuring that the lines of communication were open and that everyone had the ability to speak their mind without fear of repercussion was the most important part of brainstorming. Creating this type of an environment allowed the team to determine solutions that are best suited for a sustainable outcome. Other components of the new factory layout focused on increased throughput, less work-in-progress, and few or no bottlenecks. Furthermore, the new layout incorporated the ability for area managers to make minor changes as needed in order to adapt to variability, focused on open floor space and clear visibility, and last, but not least, paid the utmost attention to safety in all areas.

#### **4.2.8 Review Proposal**

The new designs were reviewed by the operators, assemblers, area managers, manufacturing engineers, planning department, warehouse, and all other parties who were stakeholders in the process. Changes were made after additional problems were brought to attention through stakeholder feedback.

#### **4.2.9 Feedback on Proposal – Proposal Revision**

The new design proposals take into account the future state of the factory and the impact that the changes will have. While solutions sometimes have a large positive impact in a situation, there is often a tradeoff, of smaller negative impact somewhere else in the system. Feedback from stakeholders addresses issues in the design proposal and changes are made to resolve those issues.

#### **4.2.10 Final Design Proposal**

A final proposal of the new factory layout design will be the finished product of this thesis and submitted to management for consideration. The proposal is an overall plan for transformation of the current process used, and includes milestones to successfully implementing the ideal state of the facility.



## **5. Current State and Process**

The current state is defined as the state the factory was in at the beginning of the project. This comprises of the physical layout of the plant, equipment, and tools used for the manufacturing process, as well as the path or flow that materials followed in the process.

### **5.1 Understanding the Components of the Manufacturing Process**

As this entire manufacturing process has many components and steps, it was crucial to understand the process flow leading into, and exiting out of each production stage. I started by mapping out the entire factory and mapping the material and process flow lines. This was done using Microsoft Excel at the request of the firm because they wanted a platform that everyone already knew how to use. Consideration was given to using a higher level software like Autodesk Inventor or Solid Works in order to compose a three dimensional rendering of the factory, and use other analysis components of that software, but for the time being, Excel is something that is extremely user friendly, inexpensive, already installed on all computers at the facility, and does not require hours of training in the current time frame.

The general process of remapping the new layout design and the implementation plan is shown below (Figure 2) in a flow diagram [7].

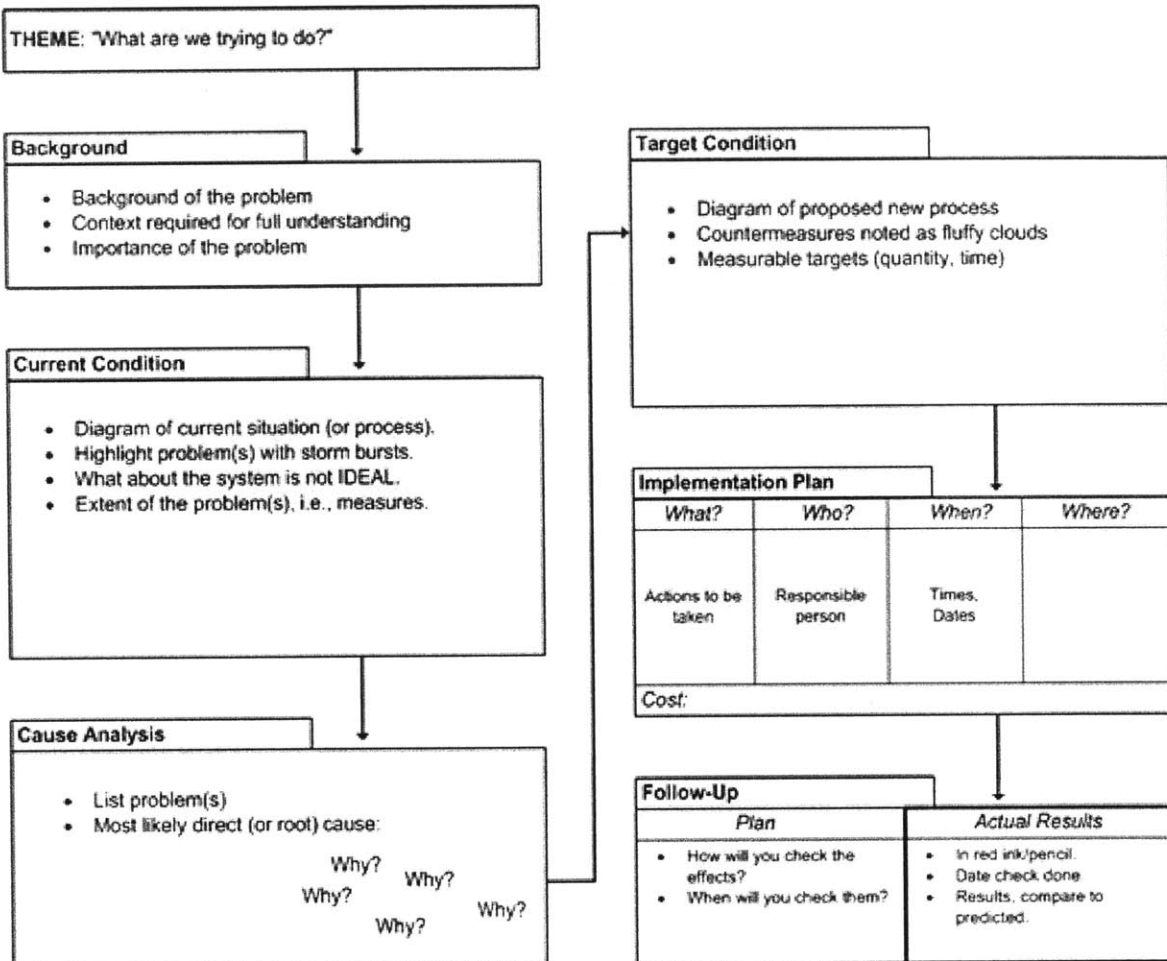
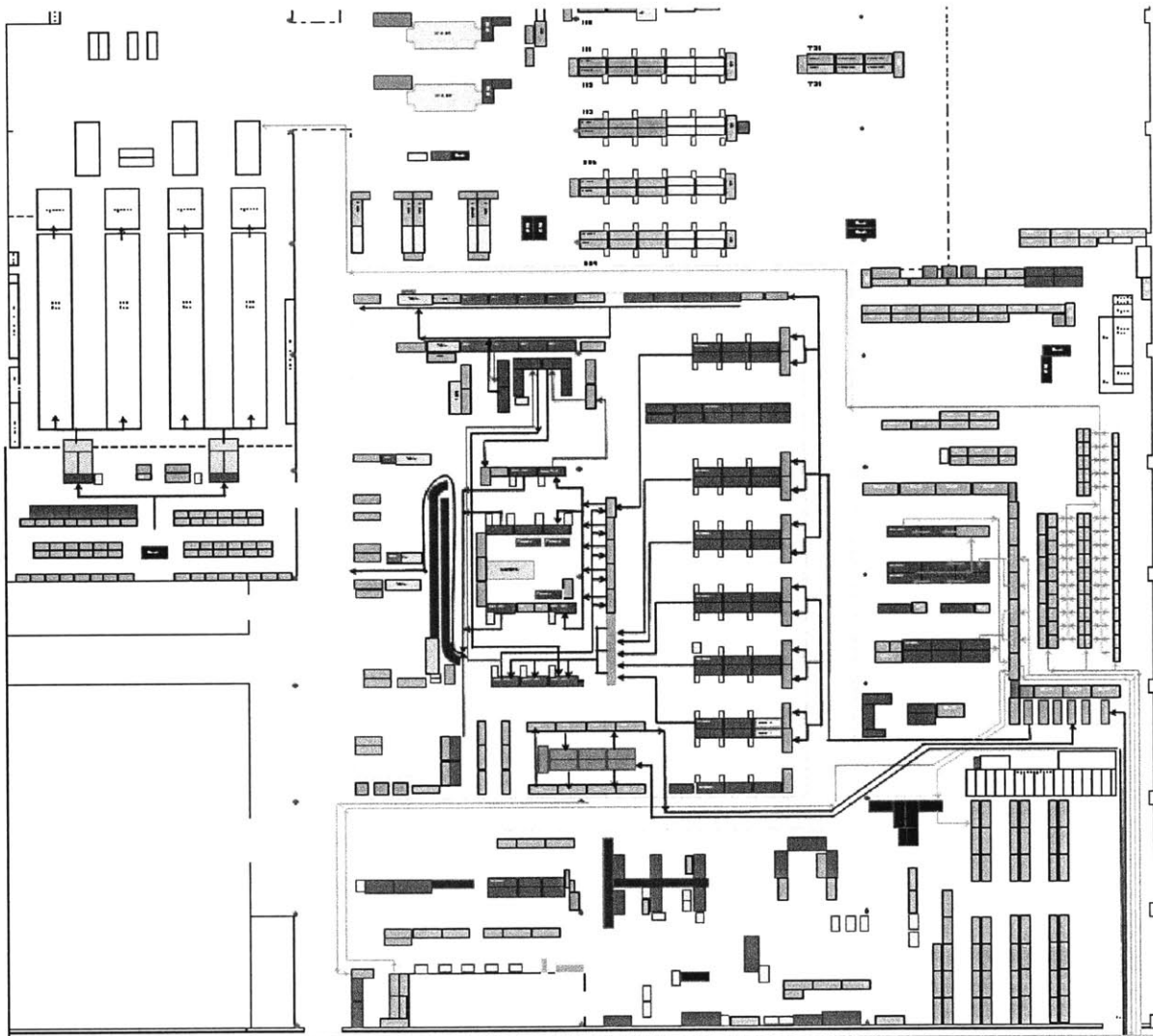


Figure 2: Methodology for Analysis

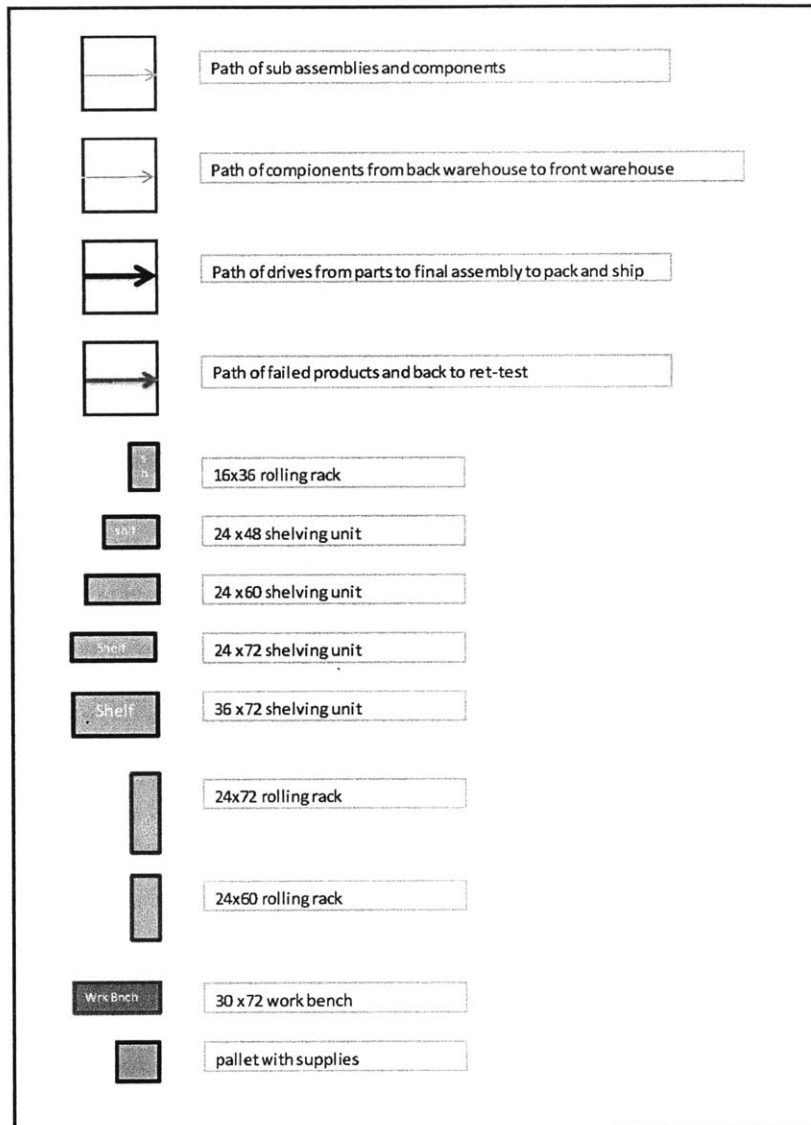
Below is the mapping of the physical layout that I composed. It is the existing layout of the facility and some of the major process and material flow paths. This system will be broken down to smaller parts in the following chapter for a better understanding of its components.



**Figure 3: Current State Mapping**

Material flow paths are distinguished from the path of failed products, subassembly components, etc. I created a general legend for this factory layout, shown in Figure 5. This general legend was also created for ease of use, implementation, and alteration of the current state; anyone involved in the planning and design process

can simply copy and paste any number of these components to the existing floor plan or start from scratch on a new floor plan idea. This was done in order to make the blueprint easy to understand and to help insure implimentation of the entire project. The excel spread sheet was formatted to 1 X 1 squares indicating 1 square foot, and all components were drawn to scale.



**Figure 4: Map Legend**

The following section breaks down the entire current plant layout (Figure 4) into subsections in order to understand the manufacturing process.

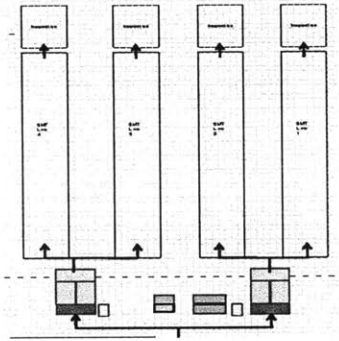


Figure 5: PCB Assembly

### 5.1.1 Printed Circuit Board (PCB) Assembly

Surface Mount Technology (SMT) machine is an automated “pick and place” machine that assembles components onto blank PCB. This is essentially the start of the assembly process. There are four lines, in parallel, at the beginning of the manufacturing process.

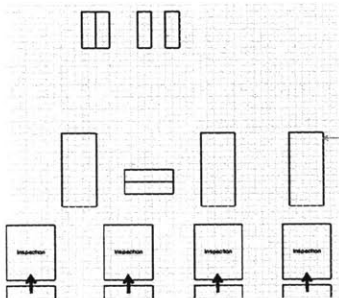


Figure 6: Through Hole Assembly

### 5.1.2 Through Hole Assembly

In this area, small components are placed onto the PCB that the pick and place machine is not capable of installing. Components that protrude through the board in order to be soldered are applied at these stations.

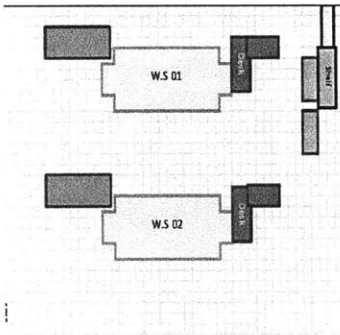


Figure 7: Wave Solder

### 5.1.3 Wave Solder

In this area the boards, with the through-hole components, are attached to a fixture and sent through the wave solder machine. The wave solder machine solders everything in one application instead of a person having to solder one connection at a time.

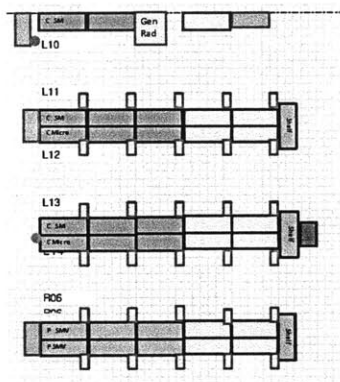


Figure 8: Board Test

### 5.1.4 Solder Touch Up and Board Test

In this area, the boards that have come through the wave solder go through a touch-up process and then to the board test area. If the board fails the test procedure, it is sent back to the touch up area for repairs. If it passes, it is put into stock and later added to a “build kit” later.

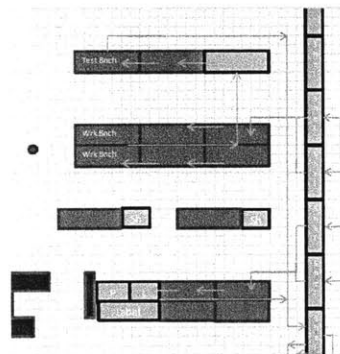


Figure 9: Sub-Assemblies

### 5.1.5 Subassemblies

In the Subassembly area, wiring harnesses are fabricated, fans are assembled onto brackets, Electronic Programming Modules (EPM) are put into housing components, and filters are assembled. Testing of these products is performed in the same area.

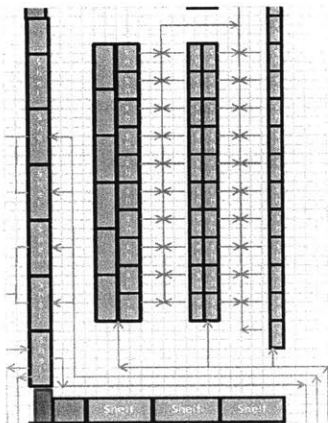


Figure 10: Floor Warehouse

### 5.1.6 On-Floor Warehouse

The on-floor warehouse is where parts are stored for the servo drive production and the through-hole production area. Parts are loaded onto a cart and wheeled to the other side of the factory. Also, in this area, the shelves on the far left (in the diagram) are where the incoming and outgoing orders for the subassembly area are placed.

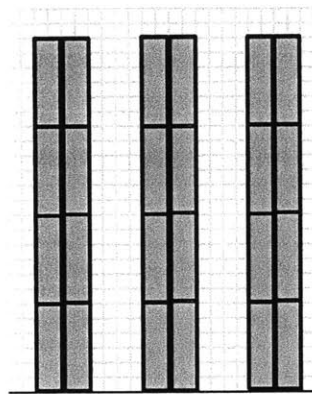


Figure 11: Rear Warehouse

### 5.1.7 Rear Warehouse

The rear warehouse is where everything else is stored for production. This includes parts that are ready for assembly, as well as raw material stock for the heat sinks that are machined in house. The warehouse also prepares and loads rolling racks (kitting racks) with build kits for the assembly lines.

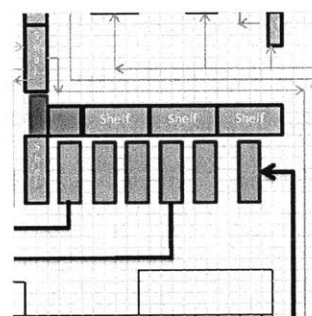


Figure 12: Staging Area

### 5.1.8 Staging Area "Parking Lot"

In this area, the kitting racks that are loaded with kits for the "drive" assembly lines are rolled out to the factory floor. These racks remain in this area until they are needed at the beginning of each assembly line.

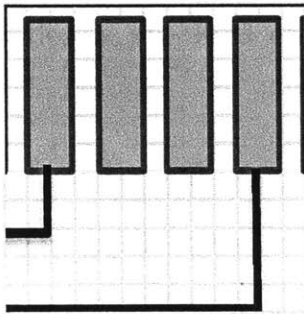


Figure 13: Kitted Racks

### 5.1.9 Kitted Racks

Kitted racks are four shelves tall on casters, and are easily moved from location to location in the factory. Components for drive assembly are on each rack and include such items as heat sinks, boards, fans, covers, capacitors, filters, etc.

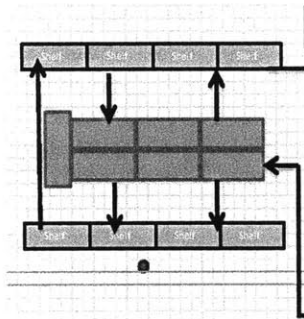


Figure 14: Drive Cover Assembly

### 5.1.10 "Drive Cover" Assembly

The covers for most of the drives have boards, wiring harnesses, and labels attached in the cover assembly area. After this process is completed, these covers merge with the drives at the end of the assembly lines.

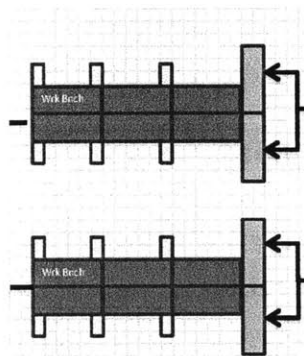


Figure 15: Drive Assembly Lines

### 5.1.11 Drive Assembly Lines

The drive assembly area consists of three benches in a row. Bench one is the assembly of the board, fan, and other components to the heat sink. Bench two is for soldering of capacitors and other components. Bench three is for inspection and attachment of the cover onto the unit.



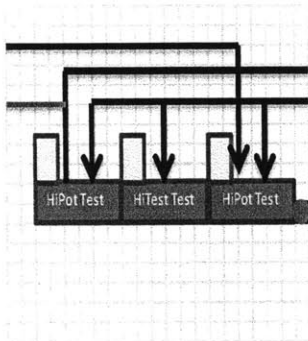


Figure 16: High Potential Testing

### 5.1.12 High-Pot Testing

After the drives are assembled, they move to the high potential (Hi-Pot) test area. Most of the drives go through this test area and then back to a shelf (buffer) where they await the next step of final test.

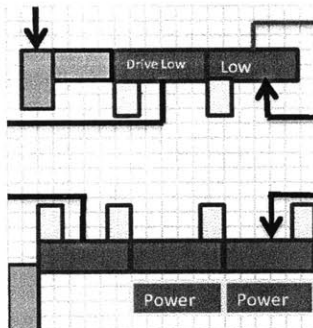


Figure 17: Final Test

### 5.1.13 Final Test

Final test is performed on each drive, depending on horsepower requirements. The test benches are sectioned in the following way: up to 5 hp, 5 hp to 10 hp, over 10 hp. If they fail inspection they kick out of the line and go to a rework area. If they pass the Hi-Pot test, they move onto packing and shipping.

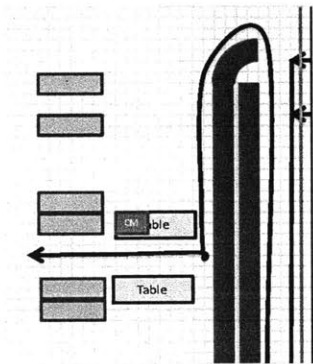


Figure 18: Packing and Shipping

### 5.1.14 Packing and Shipping

After the drives have gone through all of their final test procedures, they move to a conveyor line in the packing and shipping area where they are packaged for immediate shipping and some replenish a safety stock kept in house.

## 6. Analysis and Solutions

In the analysis of the existing process, many bottle-necks became apparent, there were several procedures that did not add any value to the process, and there was opportunity for improved throughput on production. The company was aiming for a future state of one-piece-flow (see diagram below), therefore, collaborative solutions had to keep focus on what the ultimate goals were. Each step we took in solving problems had to be aligned with transforming the current manufacturing lines into a streamlined process. The new layout also had to provide the ability to place three to five new assembly lines for the next generation of product. In doing all of this, current production could not stall, so it was very important to plan wisely when reorganizing the facility.

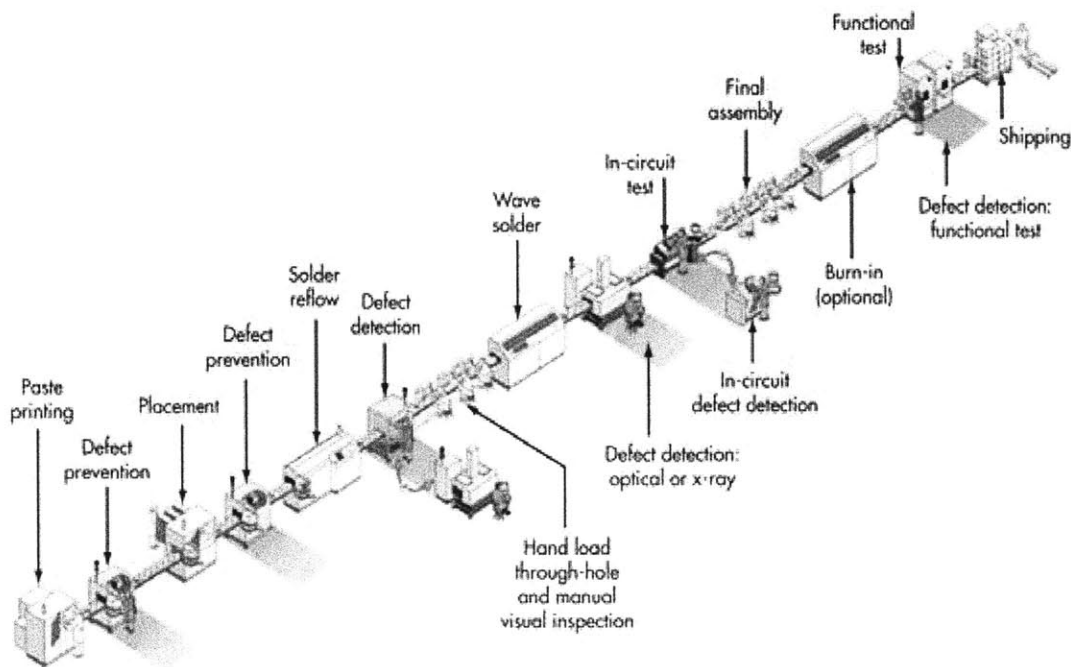


Figure 19: One Piece Flow Diagram

**General diagram of flow** - future state showing what the factory wants to emulate

## 6.1 Subassembly Area

The subassembly area consisted of numerous work benches where employees assembled parts into a larger part, i.e. a subassembly, and that subassembly would then be placed into stock as a new part number. An example of this would be a fan assembly that attaches to a heat sink on a servo drive. A fan assembly generally consists of a fan in its housing, a metal framework to attach it to the heat sink, about 4 fasteners (nuts and bolts), a wiring harness that connects to the fan, and a few other components. All of this work is performed in-house and not outsourced.

To expand further, the wiring harness consists of wire and harness clip ends, each of which is shipped to the company in bulk. The wires are cut to length, the ends are stripped, and then the appropriate clips are crimped on to each end. The wiring harness is then attached to the fan. Next, the brackets that the fans are attached to have the bolts inserted by someone at the subassembly station, and then red plastic caps are pushed over the threaded ends to temporarily hold the bolts into place until final assemblies. Many other tedious operations take place in this area, such as filter assembly and module assembly. Some of these processes might be more cost efficient to outsource the work to suppliers in order to reduce the amount of labor involved in-house. One step that needs to happen in order to evaluate the option of contracting out some of the subassemblies is time studies of current processes. In doing this, the company can evaluate what the overhead costs are for assembling these parts in-house compared to outsourced options.

When considering outsourcing sub-assembled components, it is important that we do not overlook quality and delivery capabilities. This reflects on my earlier statement of tradeoffs...the company might save money and also be more productive by having some parts outsourced, but there may also be a risk of inefficient supply chains or poor quality control. As in any decision, all factors must be weighed. The company already has some components outsourced, and relationships with sub-contractors are already established and vetted, therefore, obtaining bids from these companies would minimize some of the risk.

I conducted studies on one process (Figure 20) in order to better understand how much non-value added work was present. Further studies should be conducted and a cost benefit analysis should be performed in order to evaluate outsourcing options.

EPM - 3 boards worth @ 112 per board ( Times are in Seconds unless otherwise noted)														
Time to get boards off of shelf	240													
Verify the right amount	45													
Put bag of collars away	5													
Put collars on - Board 1 @112 units	20													
Clean of centers and inspect	32													
Stack boards	2													
Load 8 housings onto press	19	21	20	17	20	20	22	23	18	25	15	16	23	18
Press into board	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Break apart set of 8	7	7	6	7	6	6	7	7	6	6	7	7	7	7
clean and inspect each one	2	4	3	5	4	4	5	3	3	3	2	3	2	4
	3	3	3	2	2	3	3	2	3	3	4	2	3	2
	2	4	3	2	4	4	2	4	3	3	4	2	3	2
	5	2	2	3	3	3	3	3	2	3	3	3	2	2
	5	2	3	2	3	2	3	3	3	2	3	2	3	3
	4	2	2	1	2	2	3	3	4	2	3	2	2	2
	5	3	2	3	4	4	2	3	4	2	2	3	2	2
	4	2	3	2	2	3	2	2	2	3	2	3	2	2
Put collars on - Board 2 @112 units	36													
Clean of centers and inspect	35													
Stack boards	2													
Load 8 housings onto press	18	15	23	14	18	21	16	22	18	15	17	16	16	20
Press into board	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Break apart set of 8	7	7	6	7	7	7	7	7	6	7	6	6	7	6
clean and inspect each one	2	2	2	3	2	2	2	2	3	3	4	2	2	3
	4	2	2	3	2	3	2	2	3	3	2	2	2	2
	4	1	3	3	2	3	3	2	2	3	3	2	2	2
	3	2	2	3	3	2	3	3	2	3	3	2	2	3
	6	2	3	3	3	3	2	3	3	2	2	2	2	2
	4	2	3	2	2	2	2	3	2	3	2	2	2	2
	4	3	2	3	2	2	1	3	2	3	2	1	3	1
	4	3	4	3	2	4	2	2	2	3	2	2	2	2
Put collars on - Board 3 @112 units	26													
Clean of centers and inspect	42													
Stack boards	2													
Load 8 housings onto press	17	21	20	15	21	20	20	30	20	21	19	20	17	15
Press into board	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Break apart set of 8	7	7	6	7	7	6	7	6	7	6	7	7	6	7
clean and inspect each one	2	2	2	2	1	2	2	1	2	3	2	2	2	3
	2	2	3	2	2	2	1	2	2	3	2	2	5	2
	2	2	2	3	4	3	2	2	4	2	2	2	2	2
	2	3	3	2	2	1	2	2	2	3	2	2	2	6
	2	2	3	2	2	2	2	1	2	3	2	2	3	2
	3	3	2	2	1	2	1	2	2	2	2	2	2	3
	2	3	2	2	1	2	3	2	3	2	3	2	1	2
	2	3	3	3	2	1	2	2	1	2	2	2	1	2
SUM		AVG/Boar	AVG/Seto	AVG/EPM										
Time to get	240													
Verify the	45													
Put bag of	5													
Put collar	20	6.666667												
Clean of c	32	10.666667												
Stack boa	2	0.666667												
Load 8 ho	277		6.595238											
Press into	28		0.666667											
Break apa	47			1.119048										
clean and	38			0.904762										
clean and	42			1										
clean and	39			0.928571										
clean and	39			0.928571										
clean and	34			0.809524										
clean and	41			0.97619										
clean and	34			0.809524										
clean and	36			0.857143										
Total ( in Seconds)	999													
Total ( in Minutes)	16.65													
										Results				
										Total number of EPMs assembled	336	EPM		
										Total time to assemble	999	seconds		
										Assembly time/EPM	2.97	seconds/EPM		
										Percentage of time to get order of of the shelf	24.02%			
										Percentage of time snipping away board from EPM's	3.40%			
										Percentage of time of placing collar on boards	2.00%			
										Percentage of time spent cleaning (snipping the centers)	3.20%			
										Percentage of time spent loading 8 housings onto press	27.73%			
										Percentage of time spent breaking apart the groups of eight	4.70%			
										Percentage of time spent cleaning each EPM by hand	30.33%			

Figure 20: Time Trial Exam

## 6.2 Cover Assembly Area

During the Blitz Kaizen event, our group of operators, managers, and other team members walked through the process of the assembly line. During this exercise, a spaghetti diagram (Figure 21) was drawn to show help visualize the process and show the paths of material and process flow. It became apparent that the cover-assembly portion of the drive assembly had a multitude of overlapping steps, redundancies in material flow, and components were handled multiple times – a major concern for quality control and efficient operations.

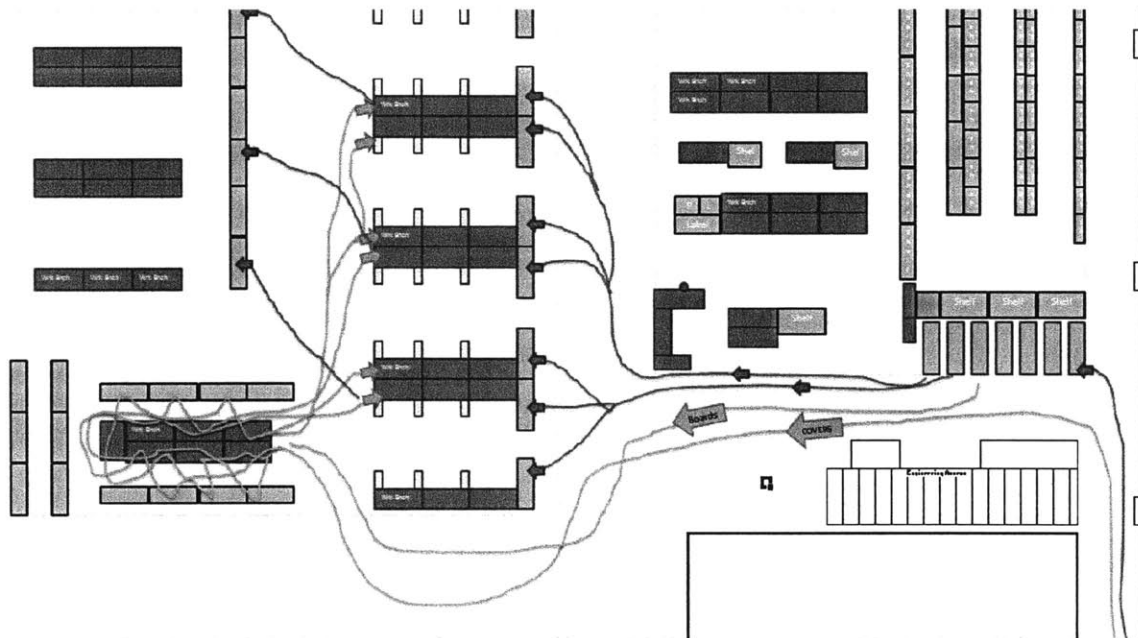


Figure 21: Process Flow Spaghetti Diagram from Kaizen Event

Orange Path: The orange path is where a warehouse worker brings boxes of covers to the cover build area, and then an operator attached labels and other components to each cover. This was done up to 48 hours before anything else for that kit was brought to the floor. After these labels and miscellaneous items were attached to the cover, the covers were placed on a shelf and remained there until the rest of the components were brought to the area.

Red Path: The red path is kitted carts brought out to the factory floor and staged for the beginning of the drive assembly lines. Some parts are removed at this point (see green line), and then the racks proceed when called for in production.

Green Path: The kitted carts contained boards and wiring harnesses that were part of the cover assembly process. When the kitted carts were brought out to the floor, the line manager had to rummage through the kits and dig out the remaining items necessary to complete the cover assembly process. These components were then brought over to the cover assembly area, and installed on the covers previously brought out to the floor (referred to in the orange path).

The improved layout of the cover assembly area is shown in figure 22. The entire process was moved over to the “parking lot” area and operation was now completed before the kitted racks were delivered to the assembly lines. The process of a warehouse worker bringing the covers out earlier than needed is now eliminated. All of the components needed to assemble the covers (Cover, Control Board, Labels, Filter, etc.) are now brought to the floor with the kitted racks, and all of those components were placed on the bottom shelf of each kitted rack for ease of access.

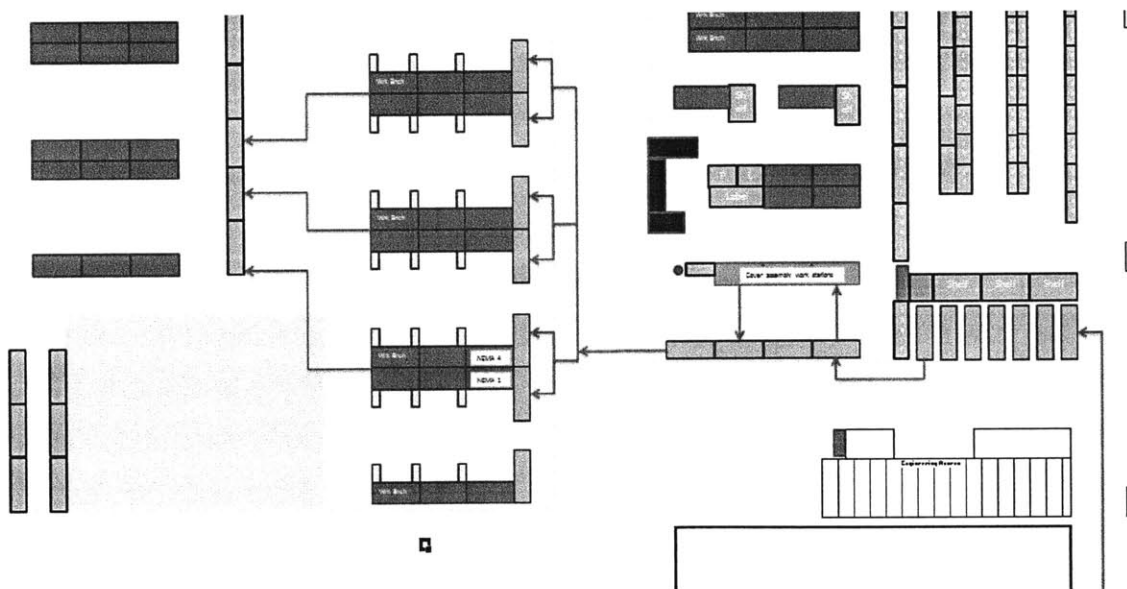
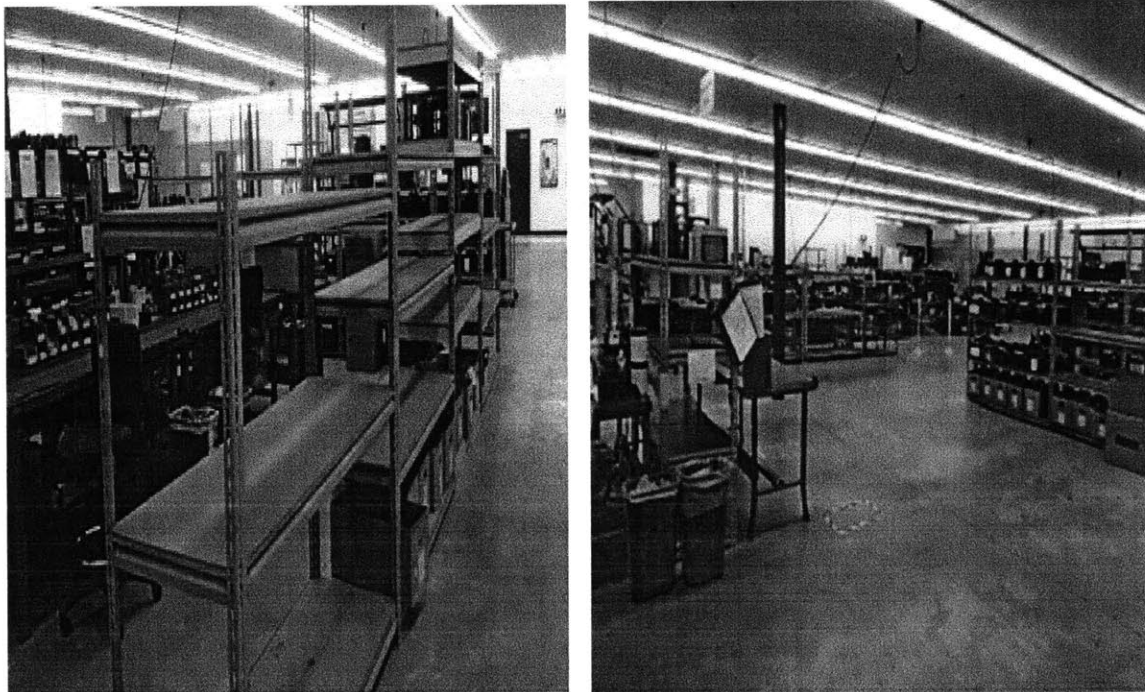


Figure 22: Redesigned Process Flow - Kaizen Event

The covers are built at the three work benches (labeled in the diagram) then put back on the kitted rack, with the rest of that particular drives components. The cover arrives to the assembly line already complete. The covers are handled less and also remain with their respective drive kit, resulting in less room for error, and a positive impact on quality control.

The buffers (8 shelving units that held up to 3000 covers in various stages of build) were eliminated from the floor. Four out of the seven benches from the cover assembly area were no longer needed because the build process was reduced to one step. The highlighted yellow area in figure 22 shows where the process used to take place. As a result of streamlining the process, over 700 square feet of factory space has been opened up. Figure 23 shows a before and after view of the area.



**Figure 23: Cover Assembly – Before and After**

### **6.3 Drive Assembly Area**

The drive assembly area consists of three benches, side by side, with each bench being designated to a certain set of work activities. The kitted racks are rolled over to the first bench and supply parts for all three benches.

On the first bench, the hardware bins were not in any particular order and made it confusing for two reasons: there was no method to how the bins were placed, and there was also no consistency from line to line. Therefore, if an assembler changed lines to help manufacture a different product, there was no common layout of hardware on the lines. A solution was to have the assemblers brainstorm on the best layout of the bins.

The second station was the solder station and the recommendation for that area was better ventilation systems, better lighting for the assemblers and to also add soldering irons to workbench 1, as soldering was the main bottleneck in this system. All assemblers are cross trained in assembly, soldering, and testing, so adding extra tooling allows assemblers to balance the line on their own.

The third bench installed the covers and performed a small bench top test. This bench typically had starvation due to the solder station bottleneck. The worker at this station could either have a soldering iron as well to increase throughput, or jump over to table one and solder there while the scheduled person at that station continues to build. When the employees were given the freedom to monitor and balance production within their respected line, they did very well.



### 6.3.1 Rack Layout

The kitted racks were extremely overloaded and inefficiently packed. Ninety-five percent of the supplies brought out to the factory floor were packaged in bulk and still in their original boxes. The assemblers spent a substantial amount of time unboxing and sorting through components and trying to navigate the supplies on the crowded rack. The assemblers spent additional time tearing down and disposing of each box. I took time studies of the assemblers and found that on average, 15% of their time was non-value added work directly related to de-trashing the racks and dealing with the cardboard boxes. In addition, the carts were loaded much higher than an assembler could reach. Furthermore, there were entire boxes of metal heat sinks that weighed a substantial amount and could injury if dropped while trying to handle. These scenarios were a huge concern for safety.



Figure 24: Kitting Rack - Before

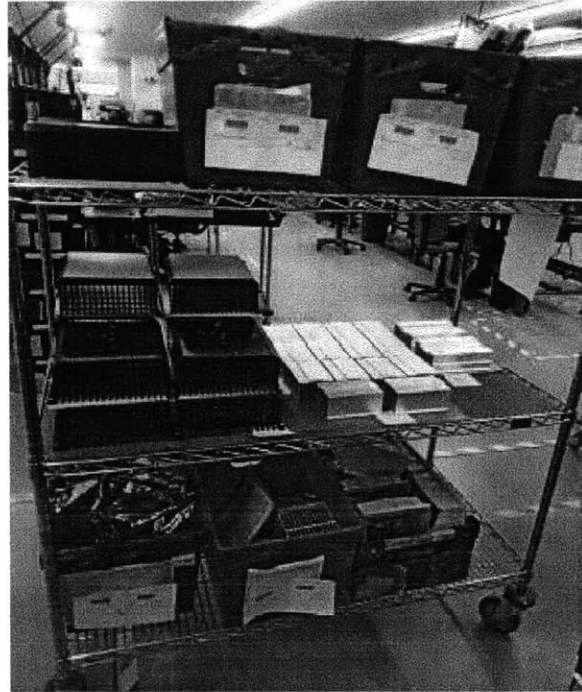


Figure 25: Kitting Rack - After

I collaborated with V. Phadnis, with the assemblers, the workers in the warehouse, and the assembly line managers, and we brainstormed better ways to load the racks. We collectively came up with a solution that would increase efficiency, decrease the risk of injuries, and reduce the amount of non-value added work (Figure 26). It was decided that the amount of reaching should be reduced. The top shelves were removed from the racks and parts were no longer placed out of reach. The racks were packed with less material, so that meant fewer jobs on each cart.

The new top shelf now contained only the components needed for assembly. Those components were removed from their packaging and placed in a bin. These bins remained with the rack and returned to the warehouse with the rack for the next batch of orders.



The second shelf would be for heat sinks only, and at a height that required limited squatting or reaching. The heat sinks were unpacked and stacked on the shelf, and the assembler could easily grab one at a time. The chance of injury from dropping an entire box of heat sinks was now eliminated.

The bottom shelf was designated for bins that held all of the material for the cover assembly stations. When organized this way, the people at the cover assembly area knew exactly where the materials would be when the racks came through their stations

Figure 26: Kitting Rack Layout Diagram

### **6.3.2 Assembly Bench Configuration**

The assembly benches consisted of a back panel that held up to 50 bins of fasteners, three to four torque screwdrivers on pull down retractable cables, and other miscellaneous hardware. Much of the assembly documentation called for four different torque specs, but the benches typically had only three. For example, many of the specifications called for 8 foot-pounds of torque, but only a 6 foot-pound driver was at their bench. The operator would use the 6 foot-pound torque driver, then let that retract, pick up a hand held screwdriver and tighten the fastener a few more turns to what they thought was about 8 foot-pounds of torque. This was not an efficient assembly process and had a negative impact on quality control. Although these drivers are on the expensive side, proper tooling is crucial for efficient operations and quality control of the product.

### **6.3.3 Hardware Management**

Multiple assembly lines built the same drives and required the same hardware, yet the benches had no standard format for placement of hardware bins. Assemblers are often moved from one station to another, depending on the manufacturing demands for a given day. There are up to 50 different hardware bins at some assembly stations, and not having a universal set up creates confusion, wastes valuable time, and can also lead to mistakes.

Furthermore, because there was no standard set up and labeling system, a bench could be missing a bin of hardware, and it would take the assembler time to look through all of the bins to verify whether he or she had all of the components needed to do the present job. We brainstormed the best solution, and one that was easy to implement. All bins of hardware and fasteners would be in the same configuration and all of the bins numerically. When an assembler came to, or left a station, he or she could quickly verify that all of the bins were present and in their proper place. With the bins all in a uniform set-up, each assembler knew exactly where components would be.

Another recommendation was that the assembler removes the bins that they need from the rack of the bins, and place those bins on the table. By segregating only the bins that are needed for the current job, the possibility of reaching into the wrong bin and installing incorrect fasteners mistakes was reduced and the amount of non-value added work was reduced. These simple steps improved the efficiency and the quality of the production at the assembly benches.

### 6.3.4 Rolling Supermarket Flexibility

In order to make the assembly lines more flexible and have the ability to assemble different drives, proper fasteners had to be available at each assembly station. The way to add flexibility to the assembly line was to incorporate a “rolling supermarket” (Figure 27). This is essentially a rolling rack that holds 100 bins of different hardware. In the event that there is extreme demand for a specific product and lines need to be converted, the rolling supermarket is brought over to the front end of the line that needs to be temporarily converted (Figure 28). It was determined that two rolling supermarkets would suffice in the event that lines needed to be converted.



Figure 28: Rolling "Super Market"



Figure 27: Rolling Cart in Front of Line

### 6.3.5 Other Improvements

The final observation was that the assembly areas lacked standardized tool layout at stations, had poor lighting for detailed assembly work, and had seating that was ergonomically efficient. The long work shifts require repetitive work, and providing simple comforts not only increases productivity, but raises the morale and the collaborative culture of the employees.

### 6.4 Blitz Kaizen Results

The Blitz Kaizen was focused on one assembly line, but some of the issues revealed in this event, like the cover assembly area, had an impact on several other lines. While the main result of the Kaizen event was the transformation of the cover assembly area, other results were a new process for the kitted racks, new set ups for fasteners on the benches, and the rolling supermarket for line flexibility. These are just initial improvements. The main focus of the event was that the employees and managers continue to identify and make improvements as a team. Communication among those members is crucial in keeping the continuous improvement process moving forward. Figure 29 shows some of the metrics that were improved as a result of restructuring the cover assembly area.

<b>Metric</b>	<b>Value</b>
Quality Improvement	Kits stay together Parts handled once
Cover Assembly Space Reduction	600 Square Feet
Cover Assembly Cycle Time	Was ~ 24 hours Now ~ 2 hours
Labor reduction	412 Hours / Year

Figure 29: Kaizen Event Results

## 6.5 Final Test Area

The final test area will undergo a restructuring process that will eventually integrate a final test bench into each assembly line. Currently, the final test area is a group of test benches in a separate area. Assembled drives are removed from a set of shelves and a Hi-Pot test is performed. There are currently only three benches designated to do strictly Hi-Pot testing and almost every drive had to undergo this test. They were then segregated into HP families (less than 5 HP, 5-10 HP, and greater than 10 HP) for final testing.

### 6.5.1 Bottlenecking in the Final Test Area

Figure 30 shows a map with flow lines of assembled drives coming into the final test area. The five black lines on the bottom right are the assembled drives being delivered to the first buffer (the shelves outlined in orange). From there, they are removed and brought to the Hi-Pot test benches (bottom left). When they are done being tested, they are placed on the remaining shelves (outlined in black). The drives are then removed from the second buffer and brought to the appropriate HP test bench. In all, there are three Hi-Pot test benches, two test benches for less than 5 HP, three test benches for 5 – 10 HP, and two test benches for over 10 HP. Two of the 5 – 10 HP benches were just upgraded to have the capability to perform the Hi-Pot and remaining tests all at one bench.

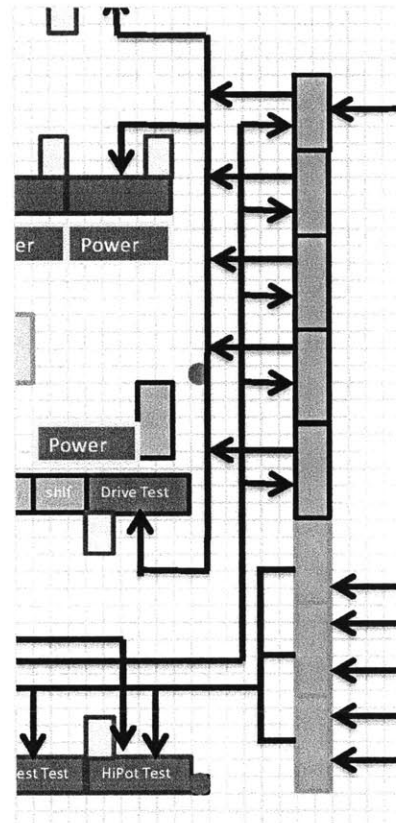


Figure 30: Test Area Bottleneck

### **6.5.2 Integrated Line Proposal**

Time studies were performed on each stage of the assembly line, and the average time for each table, in each line was between 2 and 2.5 minutes. Additional time studies showed that the process of doing the Hi-Pot and remaining tests on the integrated bench took about 2 minutes, not including initial set up of the test plate. With this information, it was determined that a pilot line should be constructed, to make sure that the process could be integrated into one line, and to see what other problems may arise.

### **6.5.3 Pilot Line for Final Test Integration**

After evaluating the line, the process of deciding what assembly line could be integrated into a new pilot line began.

After gathering input from the operators at the final test area and the assembly area, it was determined that the best possible set-up for a pilot line would be on the end of assembly line 11 (see highlighted area of figure 32). Placing the pilot line there involved a minimal amount of movement of existing benches and could be easily implemented. The proposed area was currently acting as an informal pathway; therefore, utilizing some of that space would not interfere with the existing test area material and process flow.



The highlighted yellow area in Figure 31 shows the placement of the pilot line that integrates assembly, final testing and packing. This line will act as a proof of concept for the future layout of the factory.

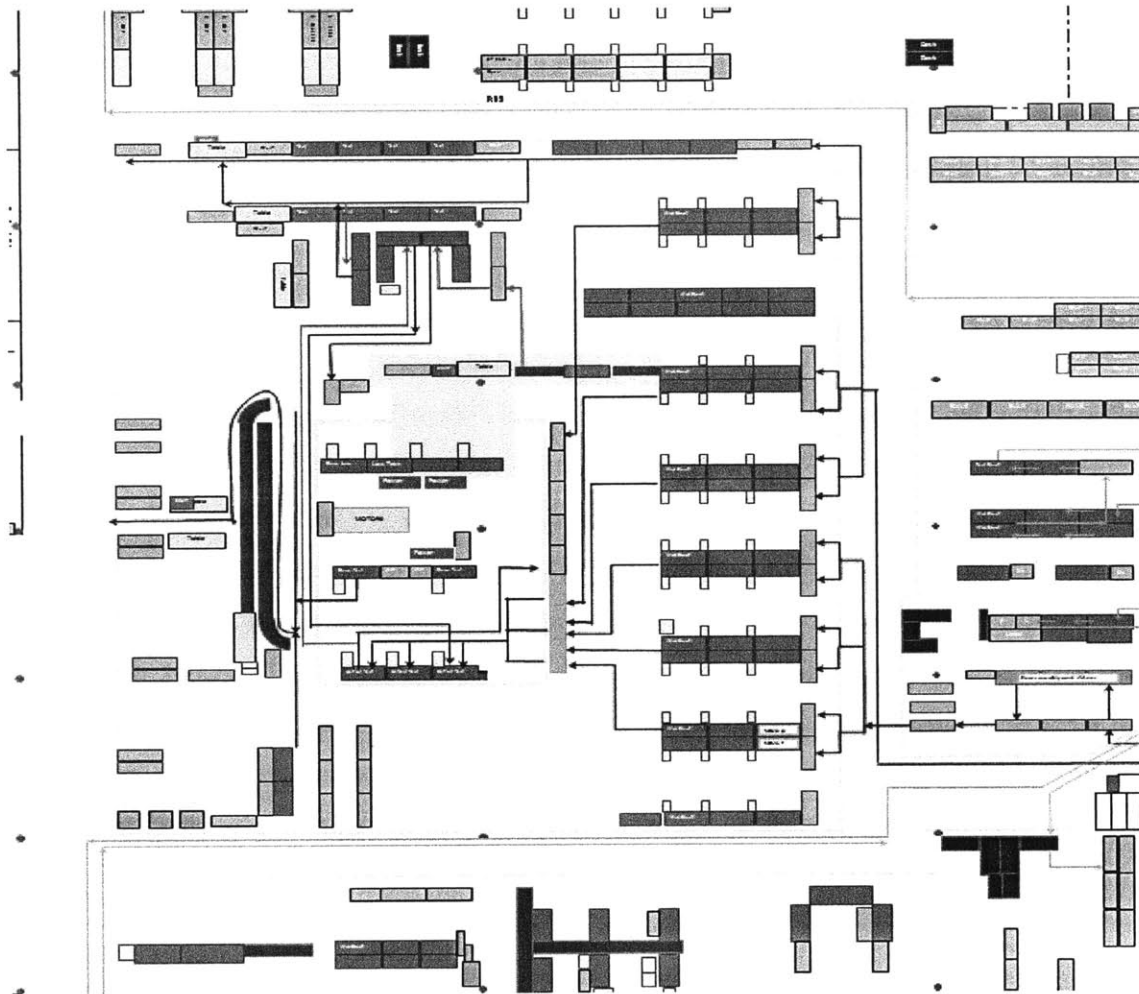


Figure 31: Blueprint with pilot test line



### 6.5.4 Integrating Assembly, Final Test, and Packaging Lines

Figure 32 shows the existing layout of the final test area. Figure 33 details the components that need to move and changes that need to be made in order to transition a final test bench, packaging, and assembly into an integrated pilot line.

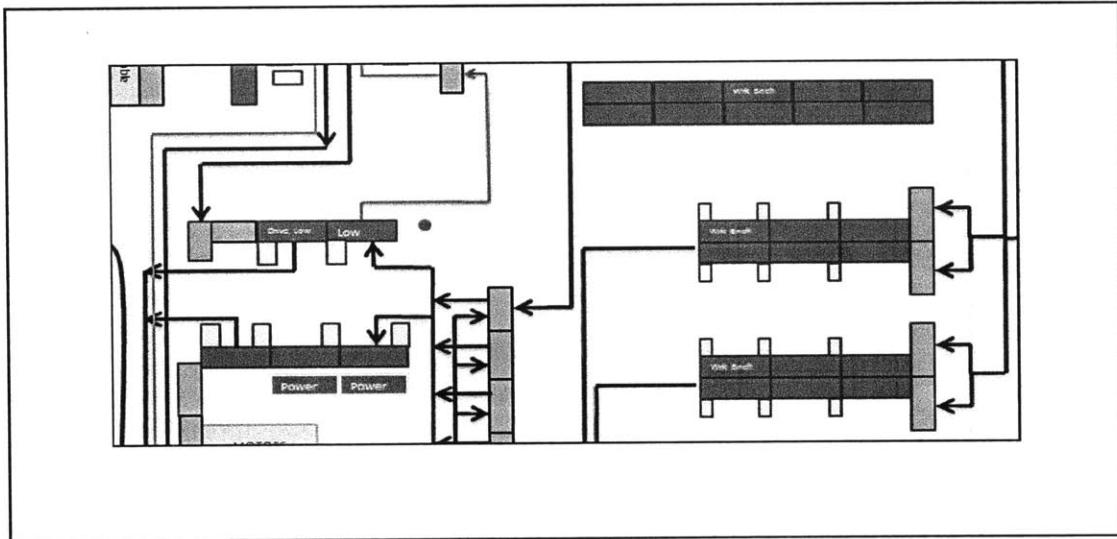


Figure 32: Integrated Test Pilot Line Area

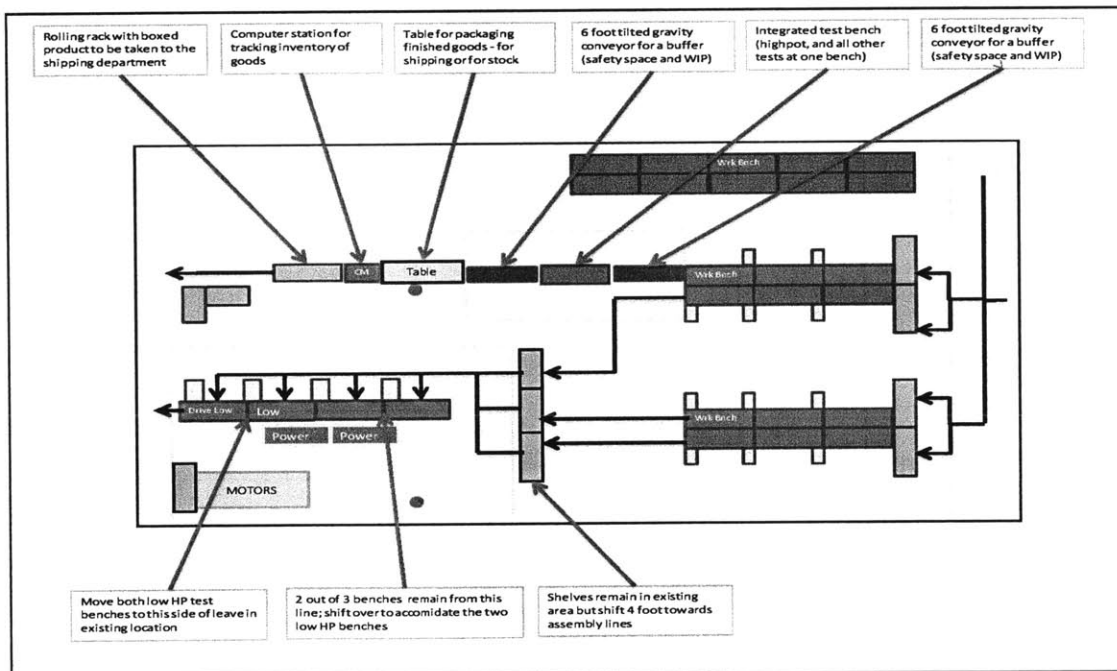


Figure 33: Proposal for Pilot Line

Figures 34, 35, and 36 show three different options for power feed considerations to the pilot line and minor changes to the existing test benches. Option 2 (Figure 35) requires the minimal amount of process disruption, minimal changes in electrical wiring, and minimal movement of the remaining benches. Option 2 is my recommendation for the pilot line placement and changes to the remaining area. After the pilot line has been implemented for a few weeks and minor problems resolved, additional changes would be made in order to incorporate the final test procedure and packaging into each assembly line. This state, where these processes are integrated into each assembly line, is the Near Term Future State and is addressed in Chapter 7.

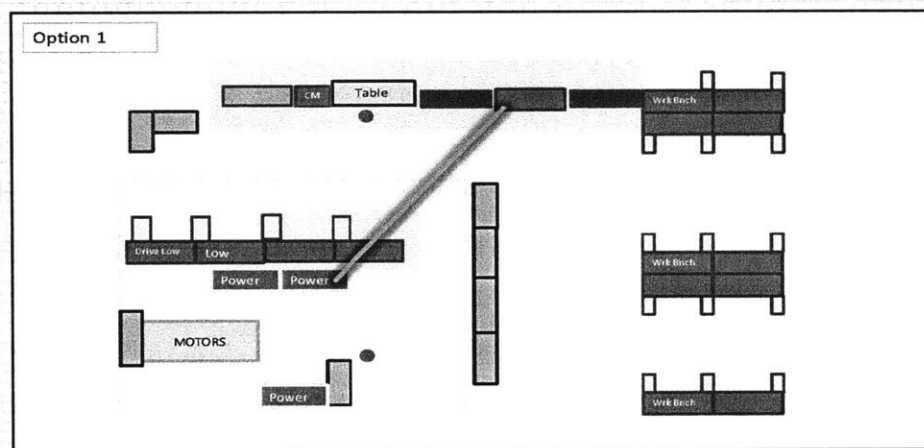


Figure 34: Pilot Proposal Option 1

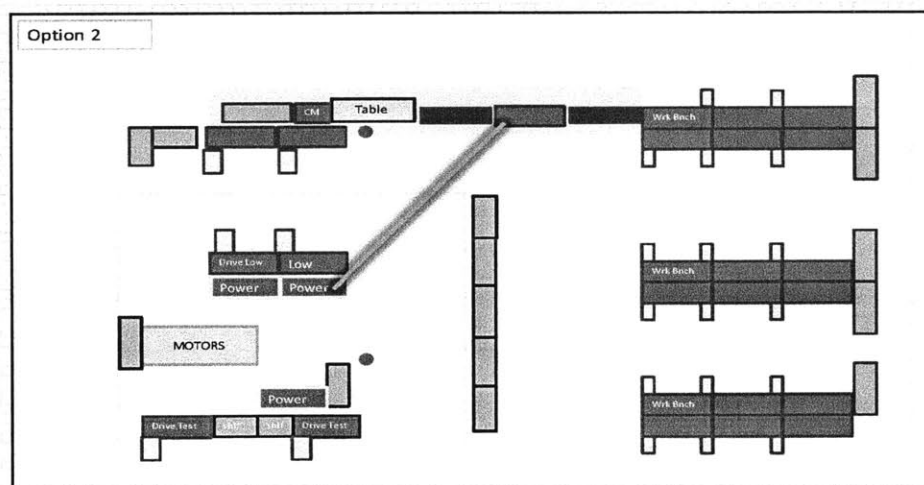


Figure 35: Pilot Proposal Option 2

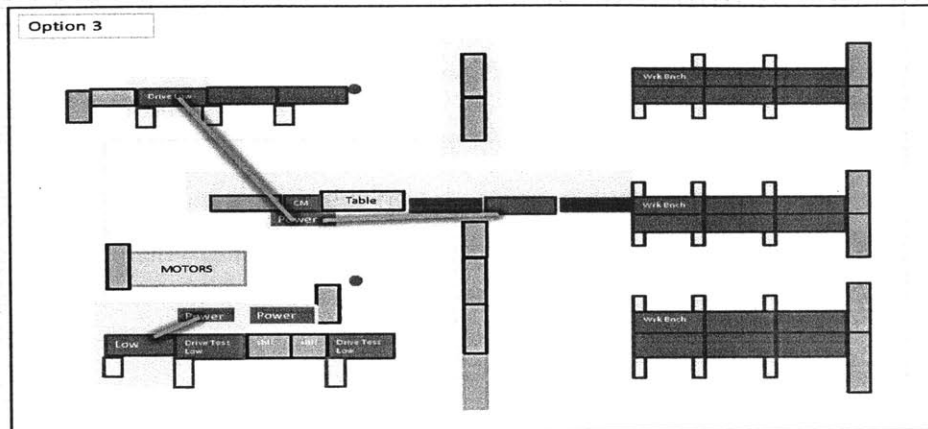


Figure 36: Pilot Proposal Option 3

## 7. Future States and Milestones

The following chapter covers recommendations and milestones of 3, 6, 9, and 12 months in order to make the necessary steps to transform the factory in two ways; a highly efficient and robust operation that implements one piece flow, and a facility that is able to incorporate up to five new automated assembly lines for manufacturing the next generation of products.

In order to accomplish this, the current production of existing products cannot be disrupted and we will should operate under the assumption demand will constantly increase during this transformation process. Therefore, each change in the current floor plan and material flow should not only anticipate floor space for integrating new machinery, but should also anticipate increased production during these steps.

This transformation process needs to happen in stages in order to evaluate occurring problems that may arise from streamlining and optimizing the layout of the current lines. This is where the continuous improvement methods need to be set in place with a solid foundation. Each one of these milestones can be altered depending on unforeseen issues and complications, but appropriate oversight, ownership, and group input will ensure a successful implementation and transition into each state.

## 7.1 Near Term Future State - 3 Month Milestone

Figure 37 shows the state of the manufacturing facility -zoomed into the servo drive assembly, final test, and packaging area - when the thesis project started. The black lines identify the path of the product during the assembly and finishing portions of the manufacturing process. There are multiple buffer areas and the material is handled a lot, and the flow of material is scattered.

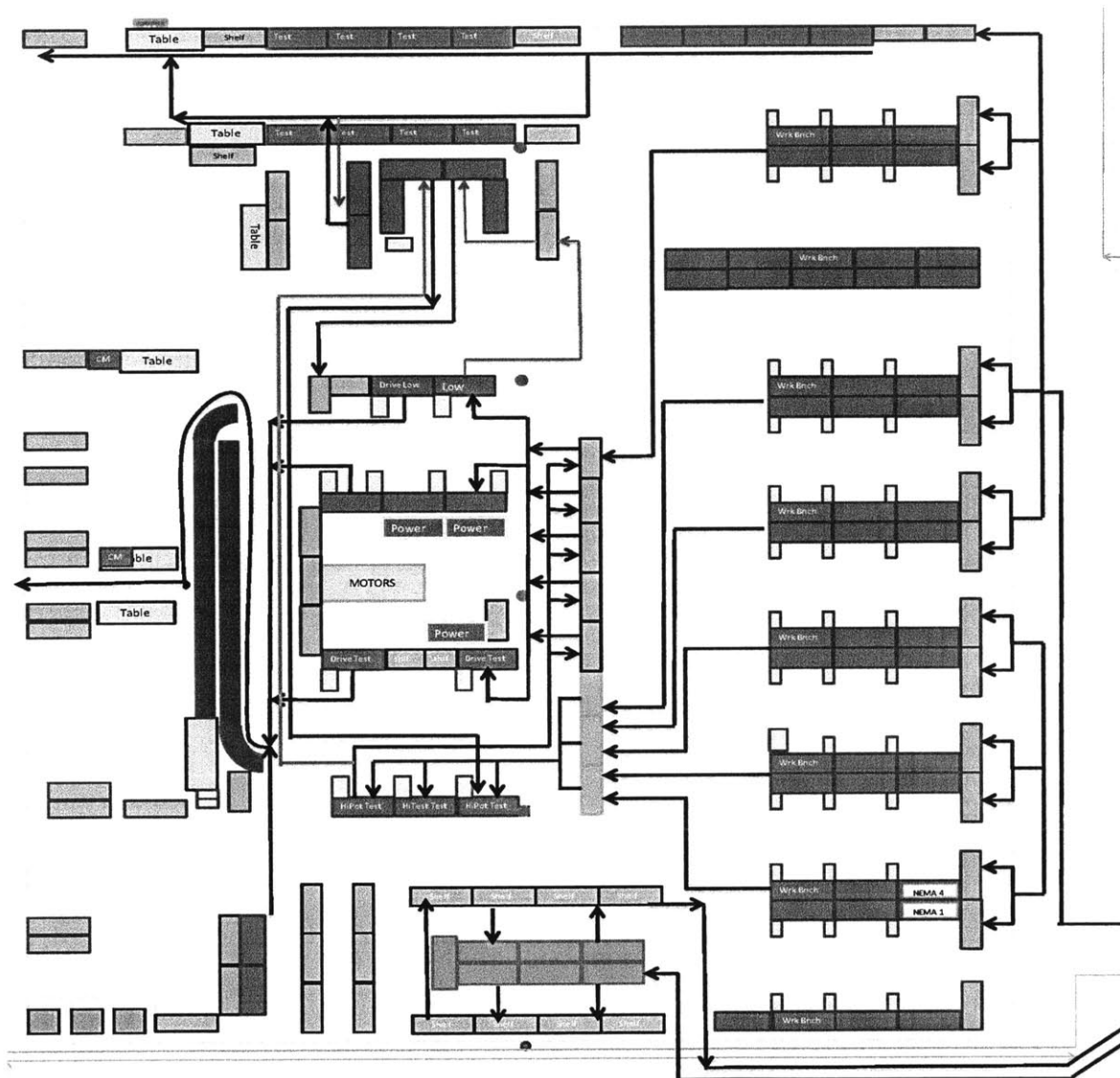


Figure 37: Current State

The design proposal for the future state streamlines the existing process, utilizes less floor space, reduces the amount of buffers in the system, and utilizes tables and work benches already present in the system. Figure 38 shows one final test bench that completes testing for two sets of assembly lines and short lengths of conveyors that send tested products to the packaging stations.

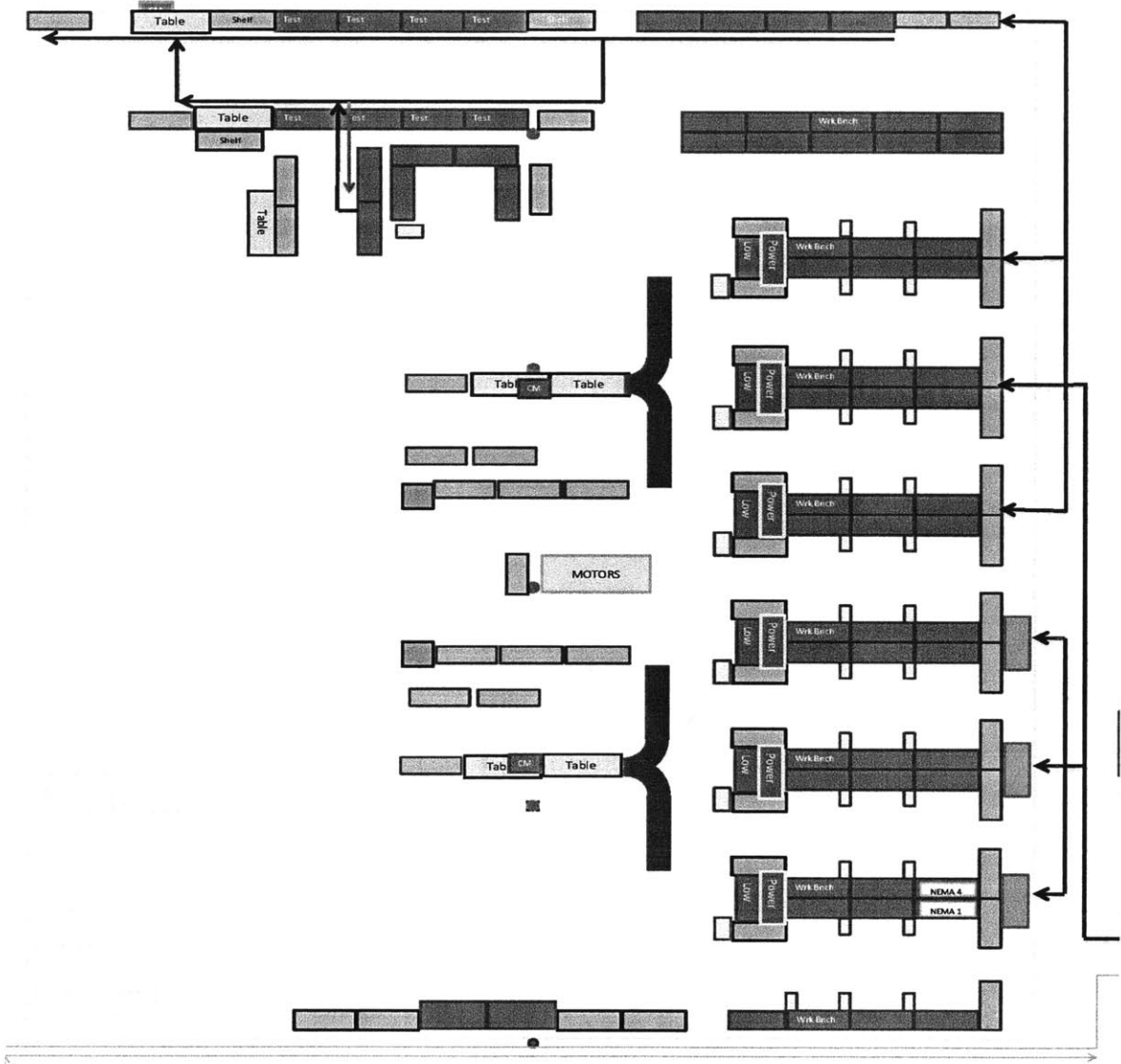


Figure 38: Integrated Test Lines

### 7.1.1 Initial Steps

Figure 39 sections out three different areas. The very top area enclosed by a rectangle with an arrow off to the right are the two wave solder machines, and they will be integrated into the end of the lines containing the pick and place machines and the ovens. The three sets of inspection benches in the middle highlighted area will be moved toward the left portion of the plant where there is open room. The bottom highlighted portion is the current final test area and will be transformed to the specifications put forth in Figure 38.

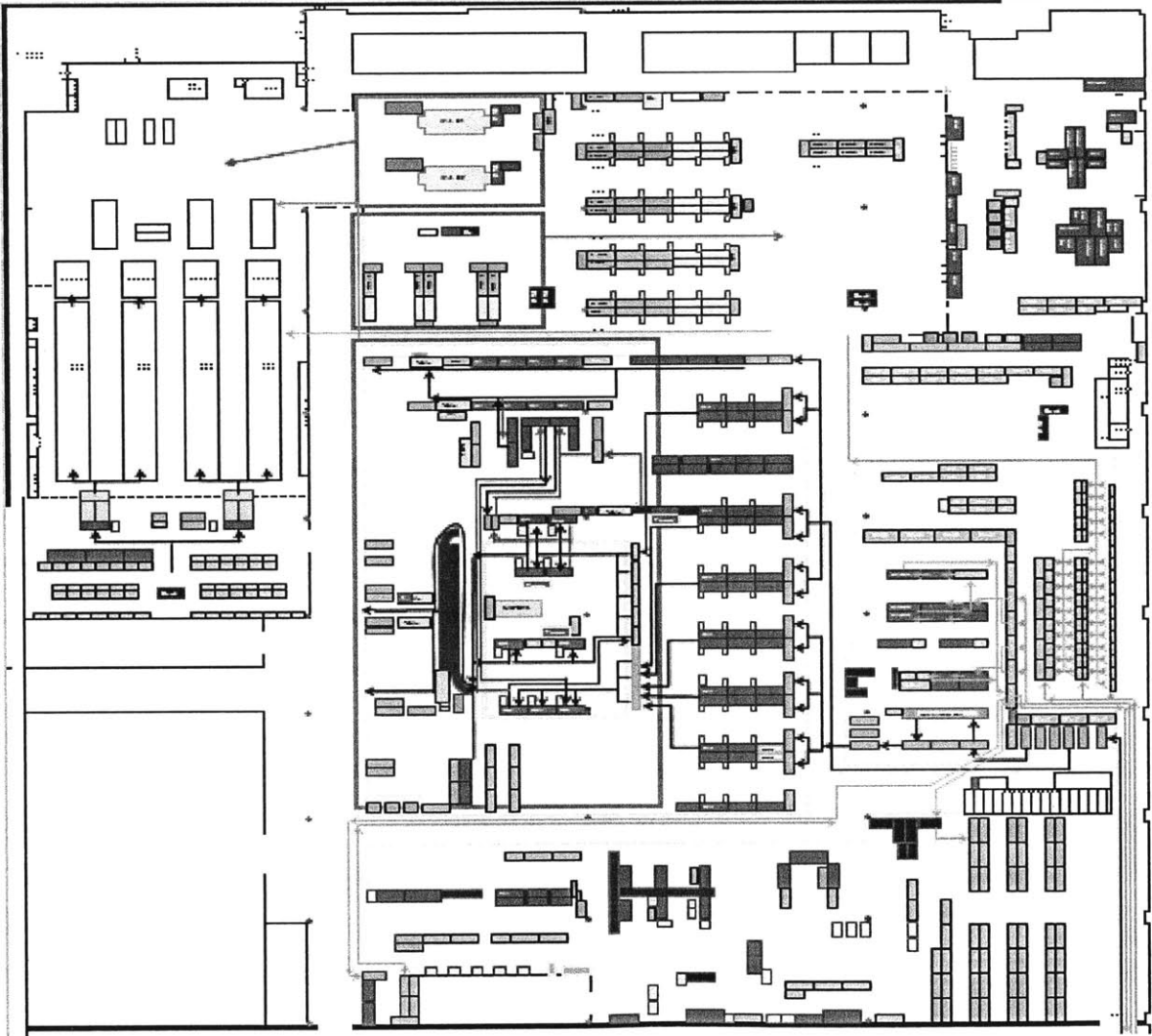


Figure 39: 3 Month Milestone - Stage 1

In order to accomplish this move without interrupting production, overtime shifts in the front portion of the line through the wave solder machines would build a temporary buffer of products immediately after the wave solder machines, allowing the front end of production to be down for a day if needed, without interrupting the rest of production.

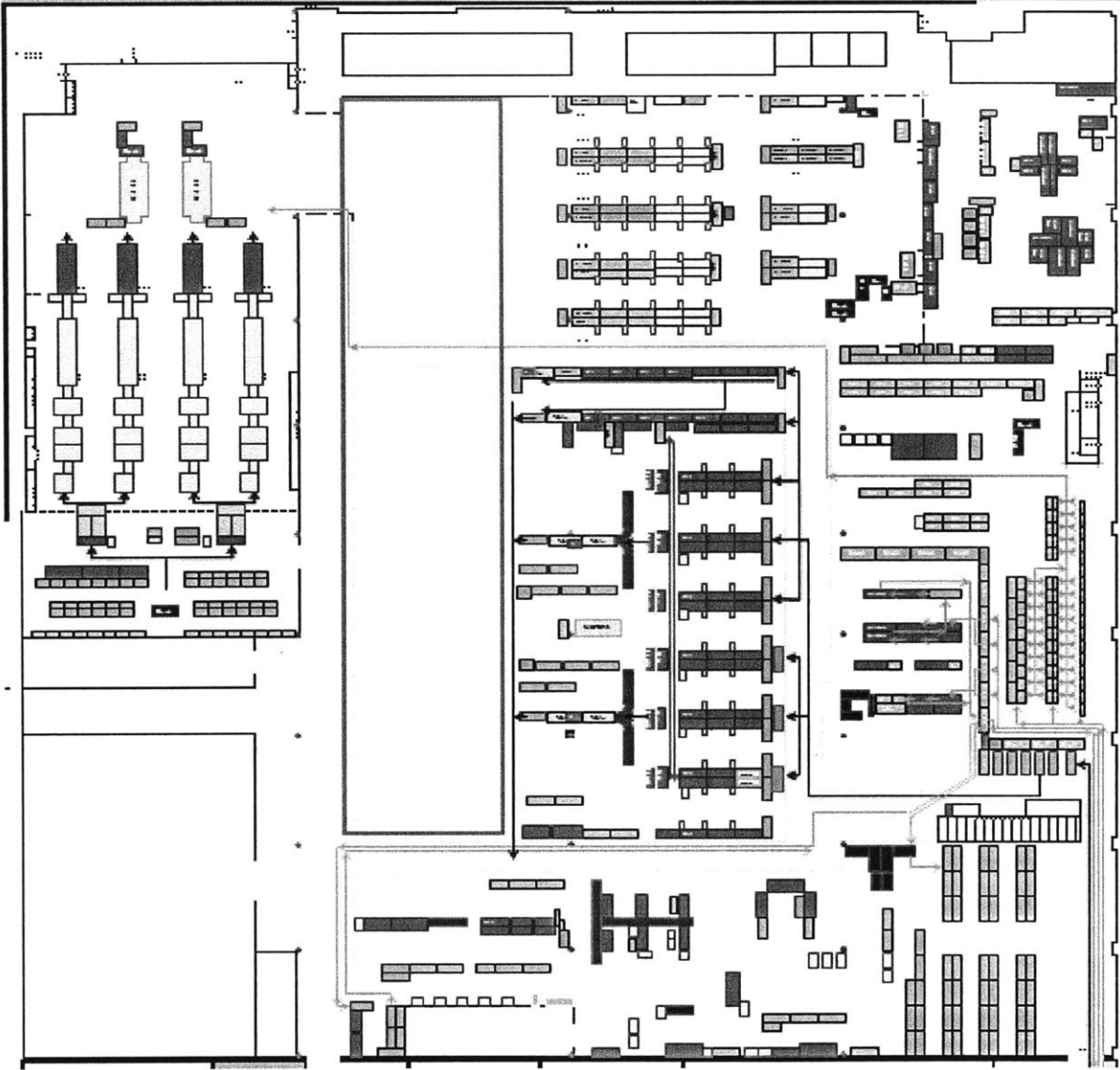


Figure 40: 3 Month Milestone - Stage 2

After the wave solder machines, test benches, and the final test are reorganized, the resulting floor plan will accommodate the first line of new machinery, shown in Figure 41.

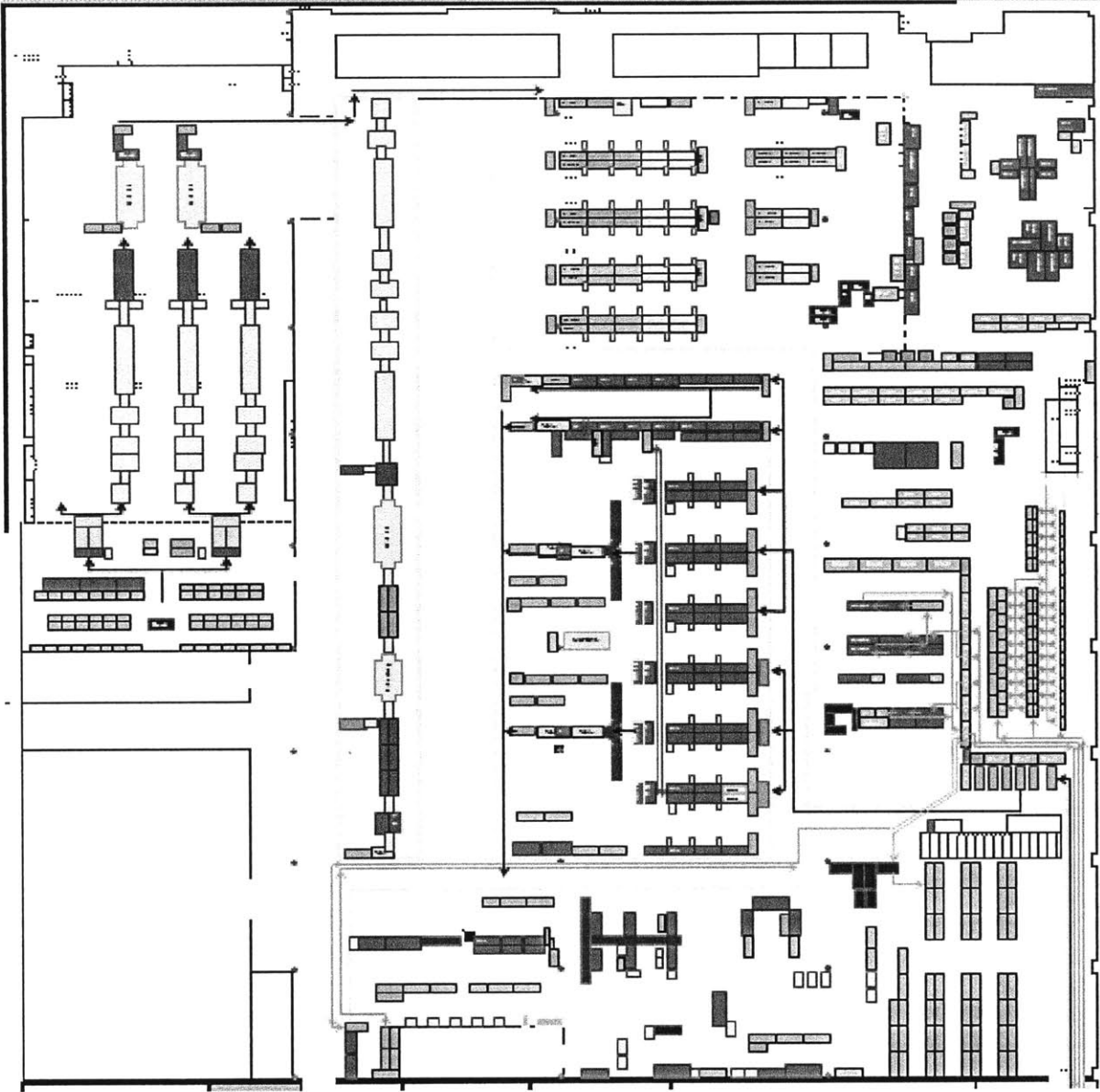


Figure 41: 3 Month Milestone - Stage 3



### **7.1.2 Recommendations for 3 Month Milestone**

It is recommended that the steps to achieve this Near Term Future State layout be implemented within the next few months, and that the final set up be complete within one year. This will leave a large aisle through the entire factory and will accommodate the equipment needed for the first set up line of the next generation (NextGen) of product. In the NextGen of product manufacturing, a lot of the steps will be automated and require a straight path from start to finish. It will be a one piece flow assembly process and will require very few buffers. Because the NextGen of product will not phase out the current products immediately, the company will continue to produce legacy products as well as the new models. Because of this, the factory has to accommodate the footprint of the new equipment (expected to be placed in the factory within 12 to 14 months) while the current footprint of existing product manufacturing shrinks until final phase out.

Note in the previous two diagrams that one line of the initial "Pick and Place" machines is removed from the current position and either integrated into the new one flow line if compatible, or phased out of use if not capable of new production requirements. This opens up some additional floor space that will be used in the next step of the factory transformation.

## 7.2 Future State – 6 Month Milestone

By the six month milestone, the new line should be in place, and in production. The next area to be moved, shown in Figure 42, is the warehouse section that is on the factory floor. A large portion of this on floor storage serves the Pick and Place machines in the front end of the production line. Other portions of this highlighted area are work benches that build sub-assemblies

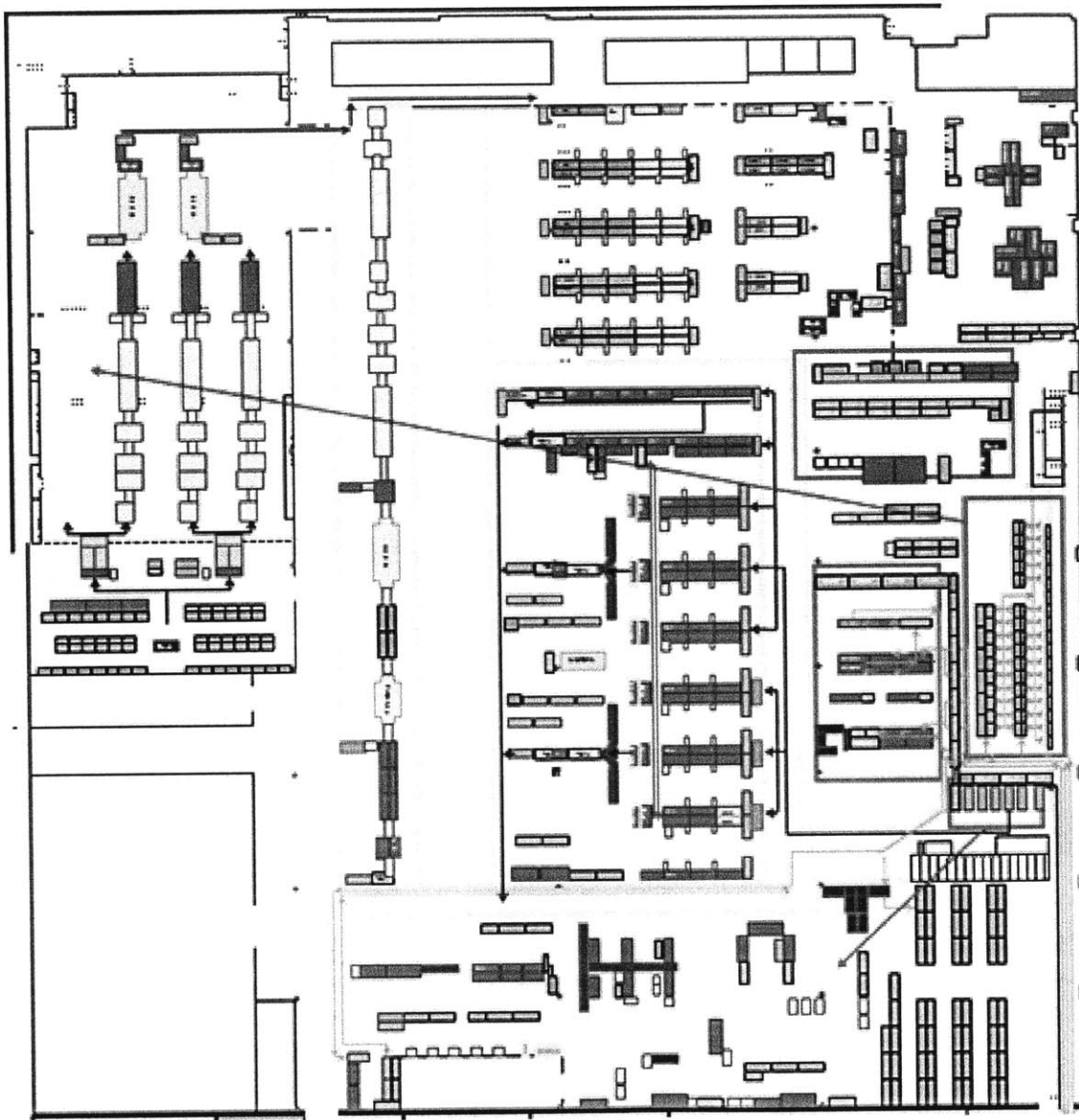


Figure 42: 6 Month Milestone - Stage 1

In Figure 43, the shelving that serves as the warehouse is now transitioned to the upper left corner of the factory floor and organized in two rows. The benches that serve as sub assembly stations are also turned by 90 degrees. Also, the cover assembly benches are integrated into the assembly lines so the “parking lot” is moved further back on the factory floor – material flow line shows new route for materials. This move opens up over 4000 additional square feet of space.

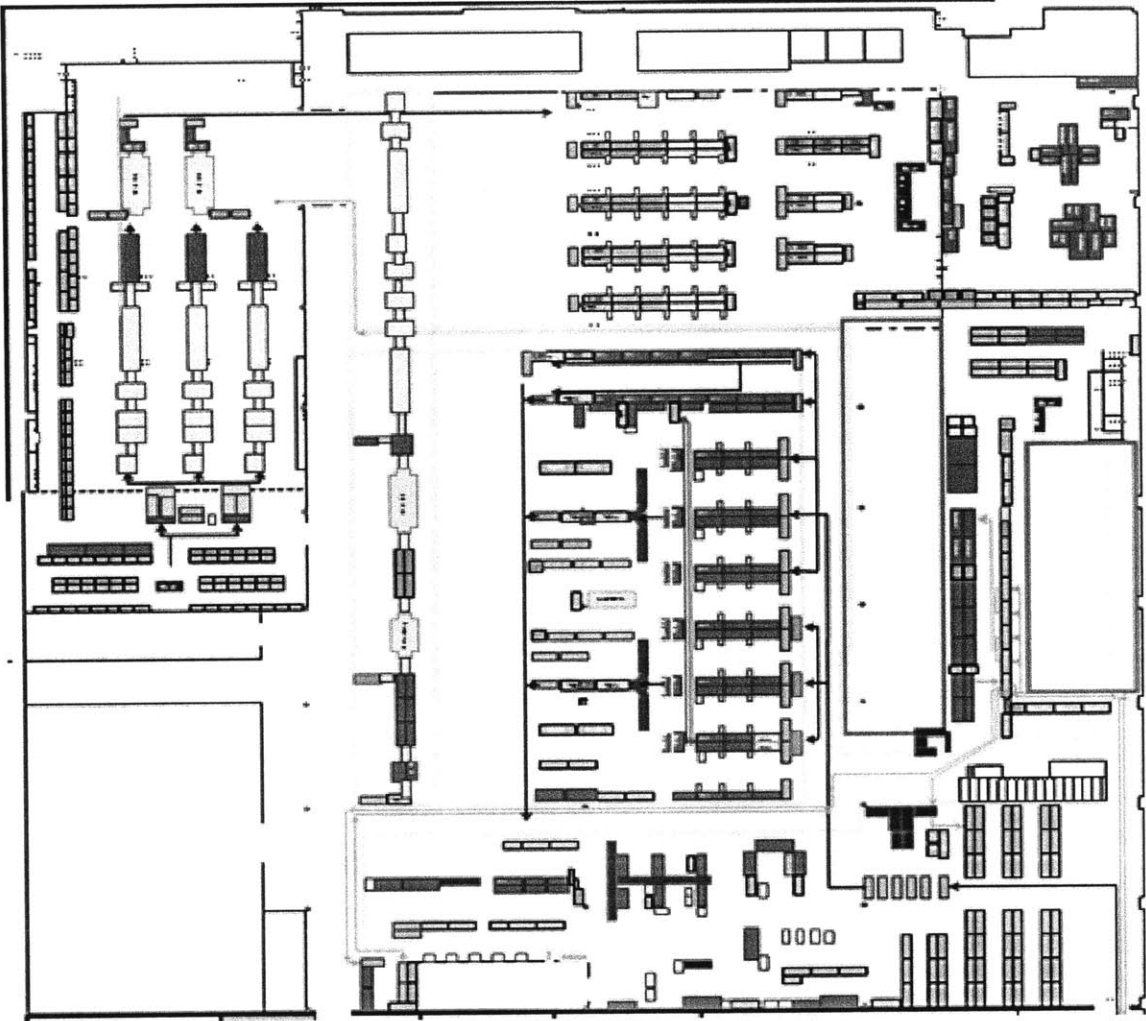


Figure 43: 6 Month Milestone - Stage 2

Once these steps are made, the sub-assembly benches, supporting materials, and supply shelves, as well as the small amount of buffer space for finished goods, are now ready to be shifted towards the outer wall of the factory, as noted by the outlining box and arrow in Figure 44.

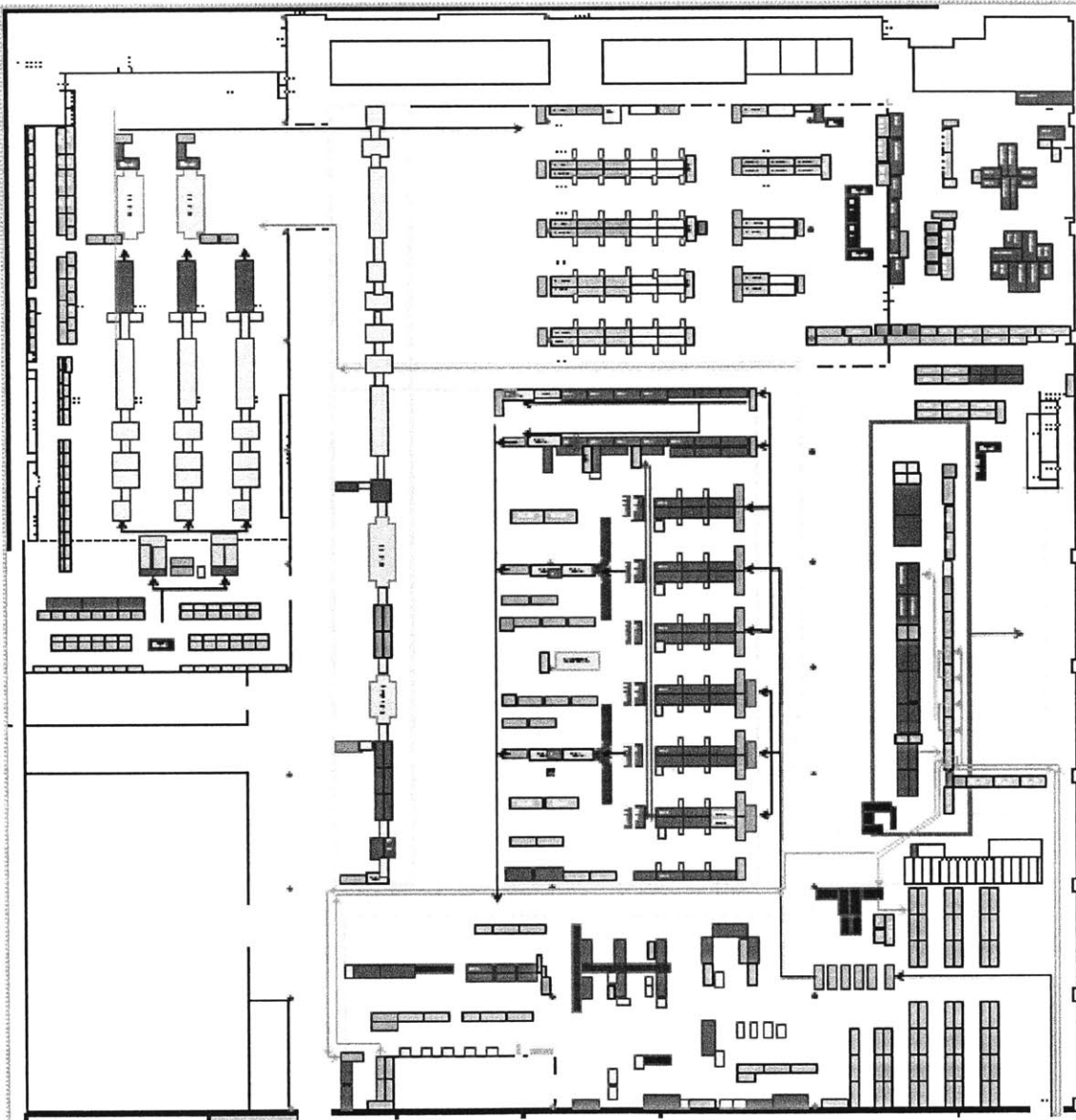


Figure 44: 6 Month Milestone – Stage 3

The conformal coating (CC) machine remains in place; other components are rearranged in order keep the process flow streamlined and efficient. The shelving units to the left of the CC machine are integrated into the row of shelving units above the CC machine, enabling the remaining work benches for the CC as well as sub assembly to all be placed neatly along the left wall of the factory.

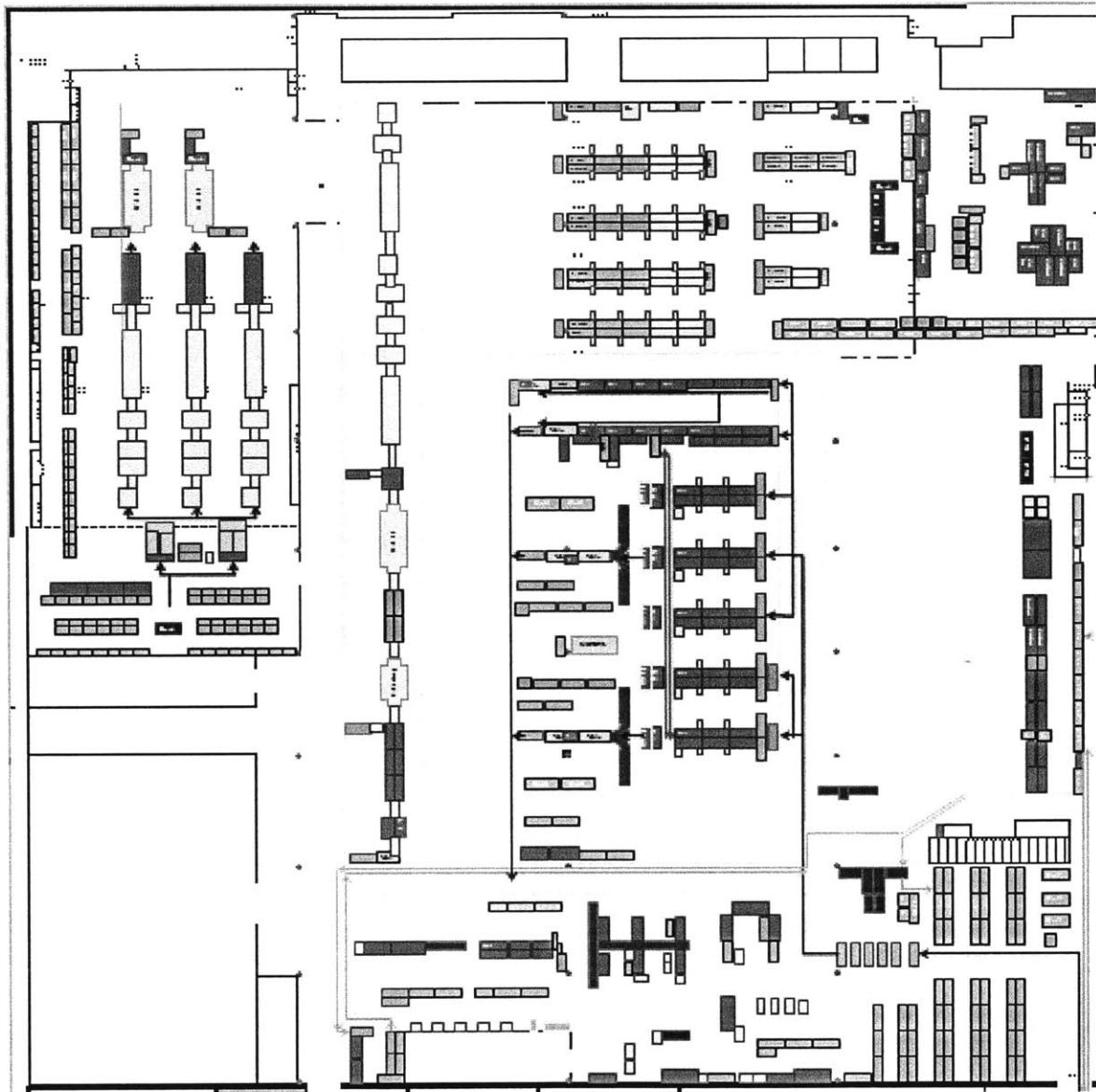


Figure 45: 6 Month Milestone – Stage 4

### **7.2.1 Recommendations for the 6 Month Milestone**

Most of the work stations that are moved in this process require a power source, so careful attention should be placed on making sure that properly grounded power outlets are installed at sufficient intervals from overhead. This upgrade needs to be performed across the entire factory and is one of the main components that should be addressed. The subassembly stations and their supporting stations that house supplies can easily be arranged into a uniform line instead of the current work set up that they are arranged in. Placing these in a single line with stations back to back requires less floor space than the existing set up and allows not just better visibility and more efficient flow of materials.

The entire section is then moved toward the left factory wall as soon as the on-floor warehouse is placed over near the Pick and Place machines in the upper right of the floor layout. Essentially, if the on-floor warehouse area is moved first, the entire sub-assembly and support area can be moved directly into its final location. The order in which these steps are performed is dependent upon production scheduling and manpower. These steps can be performed during regular hours of operation and will not require a large amount of downtime so long as sub assembly benches are agile enough to handle work from benches not in operation during the transition.

### 7.3 Future State – 9 Month Milestone

In order to get to the next milestone, some large shifts are made in the next steps. In Figure 46, the entire section in the middle of the factory (cover build, assembly, final test, and packing) are all going to be shifted towards the left side of the factory while retaining the same footprint. More notes on this step are covered section (7.3.1).

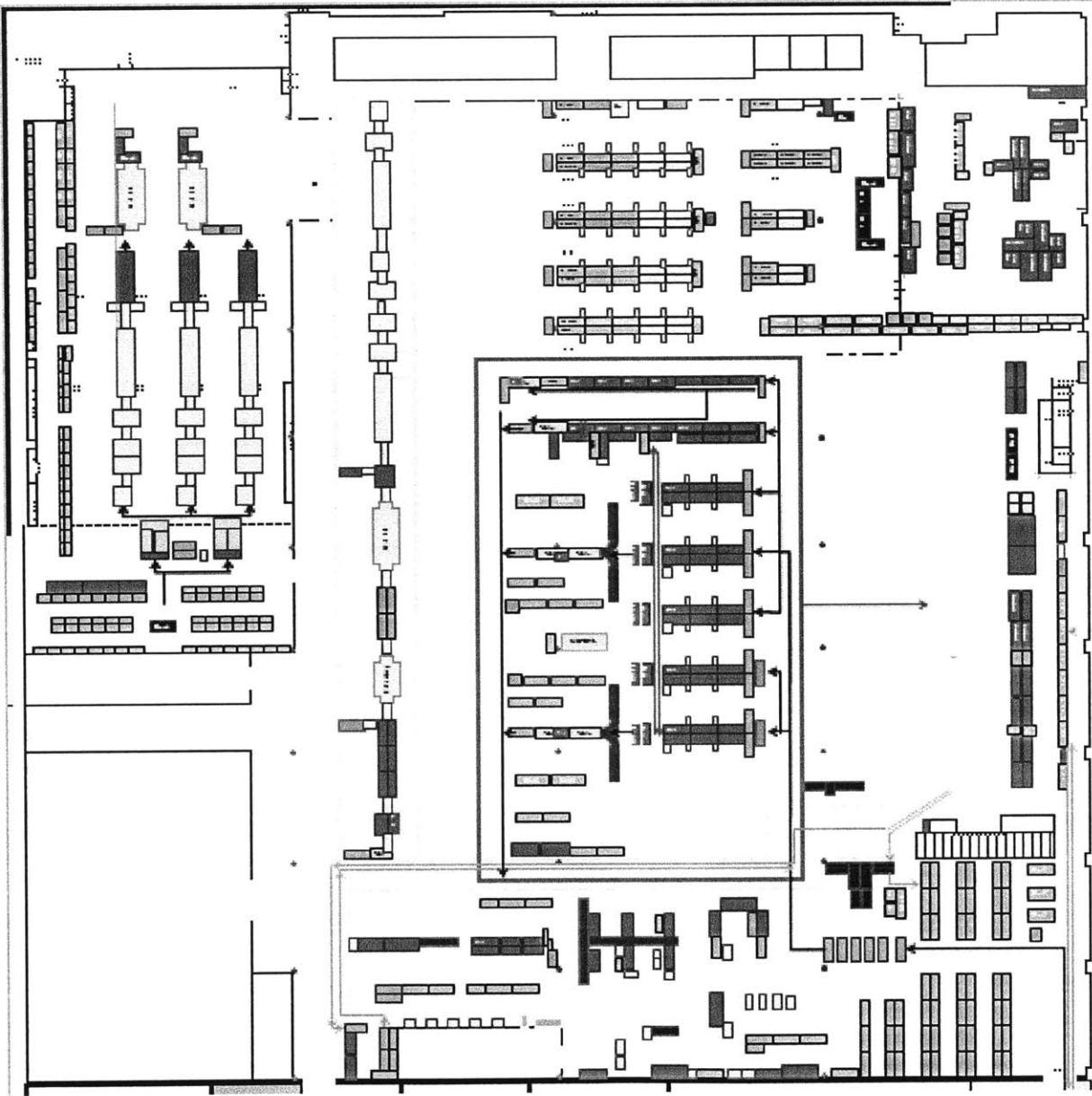


Figure 46: 9 Month Milestone – Stage 1

Figure 47 shows the factory footprint after the assembly and test section are moved. The process/material flow lines change as well, but final products are still routed to the same aisle as before. Moving this area requires preliminary wiring of electrical feed to accommodate the power requirements of the test benches. This move is the final step that opens up over 14,000 square feet of floor space in the middle of the factory.

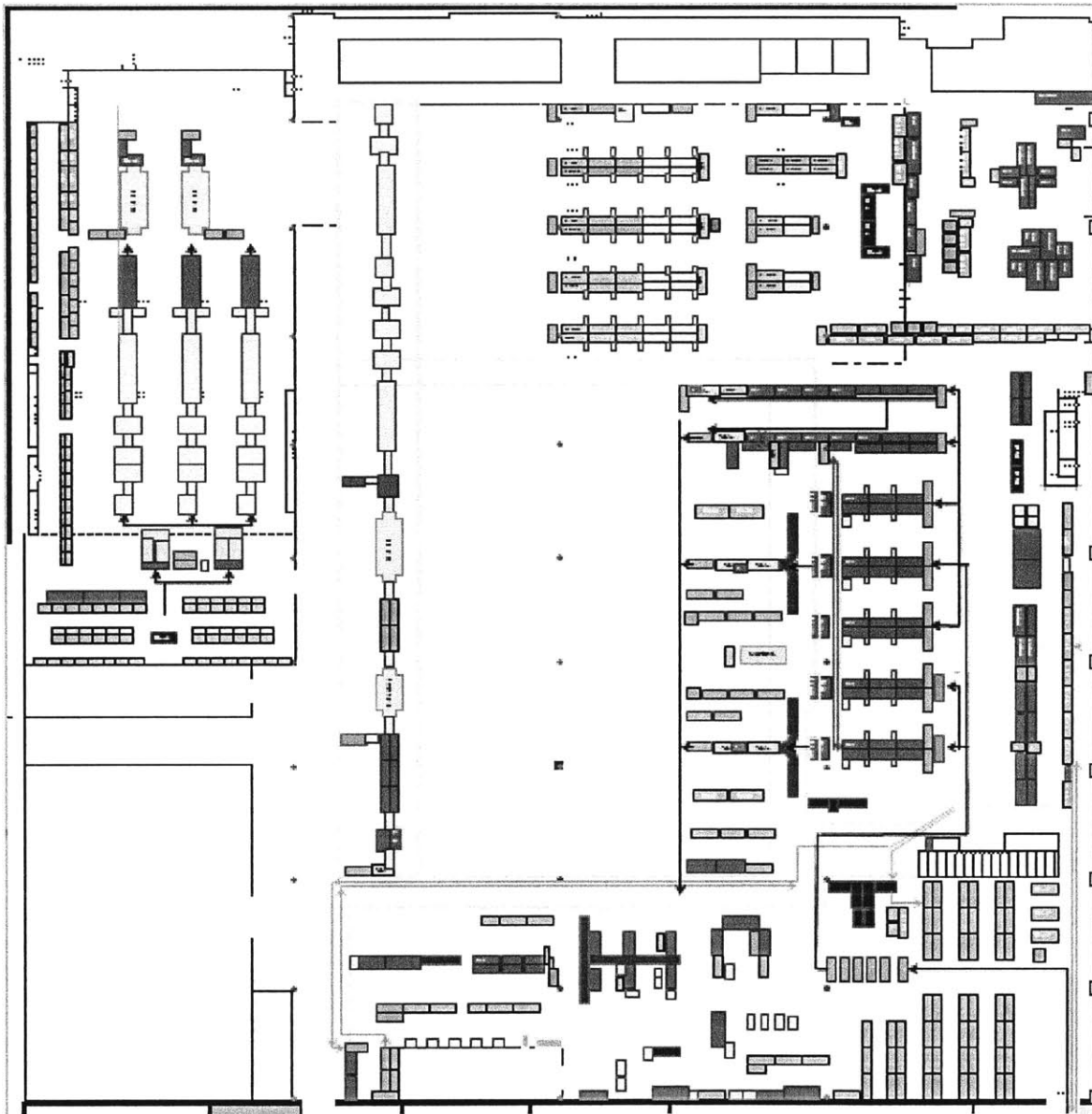


Figure 47: 9 Month Milestone – Stage 2



In Figure 48, we start to see the larger area of floor space opening up in the middle of the factory; this space will ultimately house two additional manufacturing lines. The highlighted areas in this diagram are work benches that perform touch up soldering and testing, and will need to be consolidated

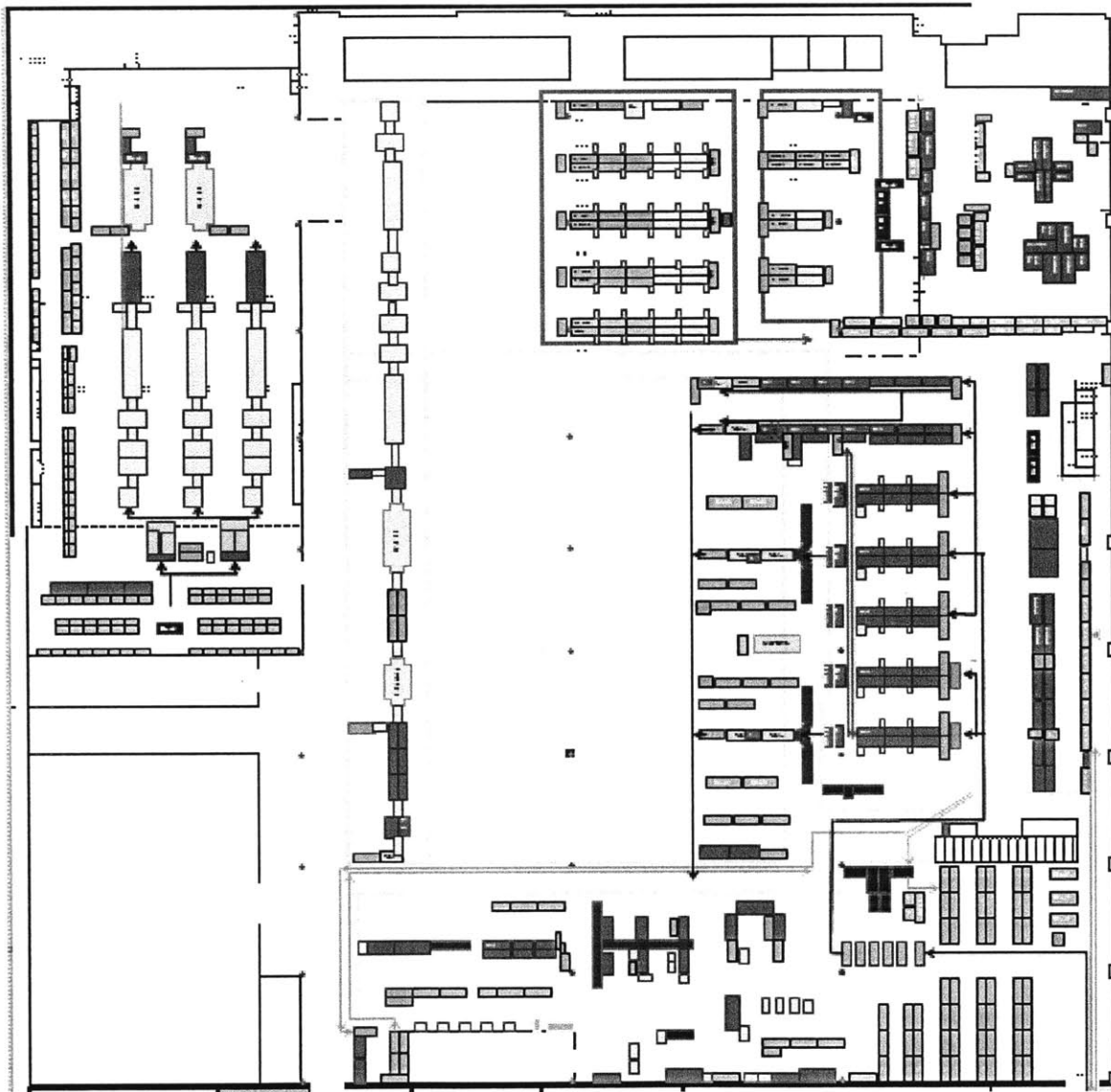


Figure 48: 9 Month Milestone – Stage 3

The amount of touch up benches can now be reduced as the first one piece flow line has been up and operating for several months by this time. Therefore, it is projected that touch up work will be reduced. Also, testing benches can be reduced because the new line has integrated test benches. Because of this, the area can be consolidated resulting in the floor plan shown in Figure 49.

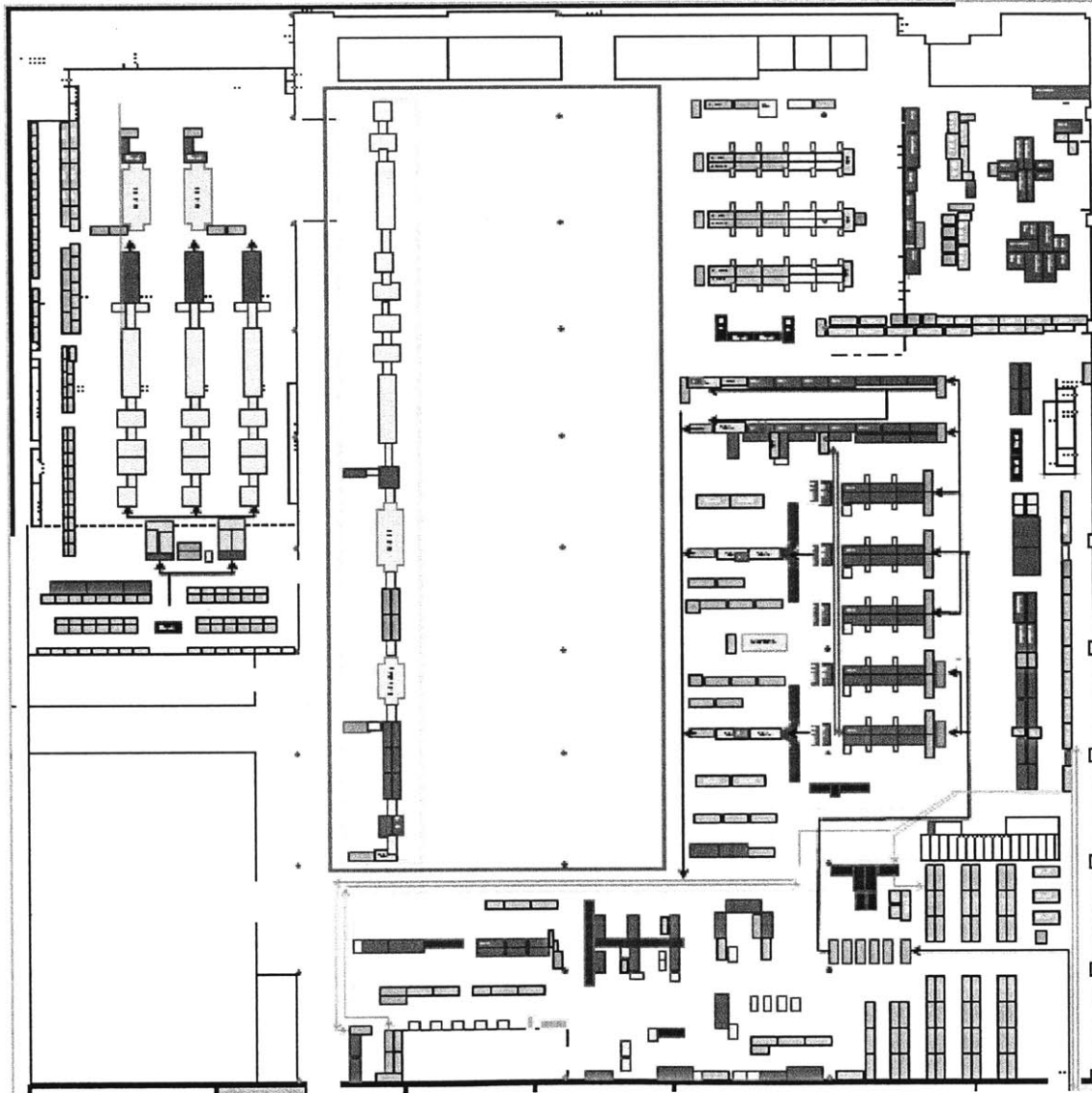


Figure 49: 9 Month Milestone – Stage 4

### **7.3.1 Recommendations for the 9 Month Milestone**

The entire section that now contains integrated cover build, assembly, final test, and packaging now has to shift as a unit. It is recommended that the top three lines be shifted to the right while the bottom three are in operations, and then once the top three lines are moved and operational, the bottom three can be shifted. If orchestrated properly, the entire shift could be performed in a 24 hour period, provided preliminary steps are made with respect to wiring and computer connections being run ahead of time.

Shifting the work benches that perform the solder touch up and testing require a minimal amount of wiring adaptation as the electrical and computer connection infrastructure already exists in that area. However, this is the opportune time to upgrade any ungrounded connections and ensure that all components meet or exceed code.

The steps to reach the nine month milestone are not too complicated, and ideally could be reached earlier if needed. Accelerating this portion greatly depends on the ability of the company to upgrade its electrical infrastructure and the ability for proper planning of not just the move, but anticipation of unexpected problems, and the ability to quickly resolve them. Hence moving the assembly, test, packing sections in two smaller subsections allows production to continue, albeit at a reduced rate, but anticipates any unforeseen problems without completely halting operations.

### 7.4 Future State - 12 Month Milestone

As shown in Figure 50, the nine month milestone, two modern assembly lines are in place and room to accommodate a third is also available. The portion highlighted in the upper right of the floor plan is a test and troubleshooting area that will be reconfigured to take up less floor space, yet use the same amount of benches and storage shelves.

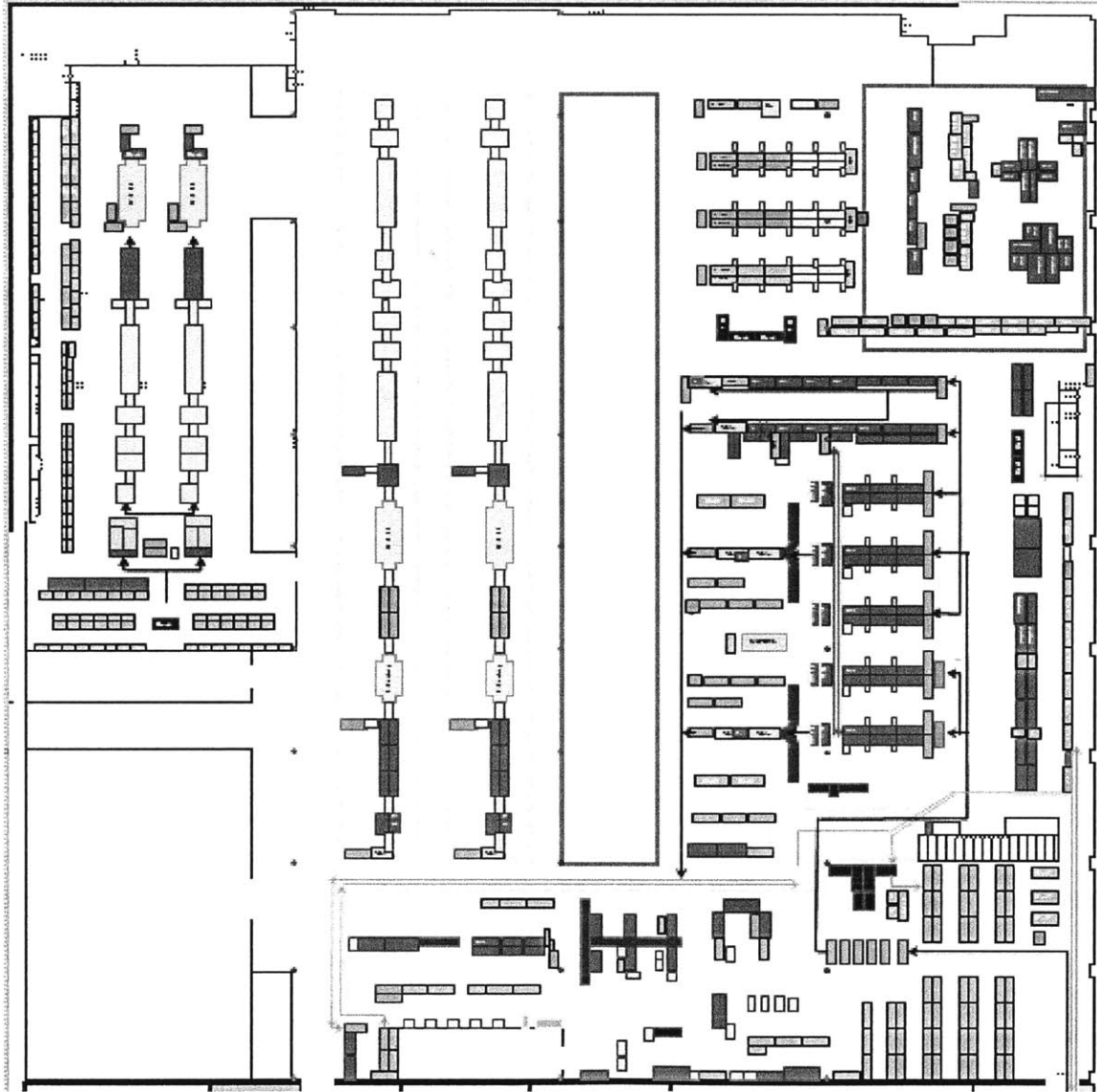


Figure 50: 12 Month Milestone – Stage 1

In Figure 51, engineering and support offices are now moved; supply shelves run the length of the wall at the head of the manufacturing lines and three of the “one piece flows are in place. With three lines functioning, it is anticipated that some of the lines that support the legacy products will be utilized less and can start to be condensed and converted to an agile manufacturing setup.

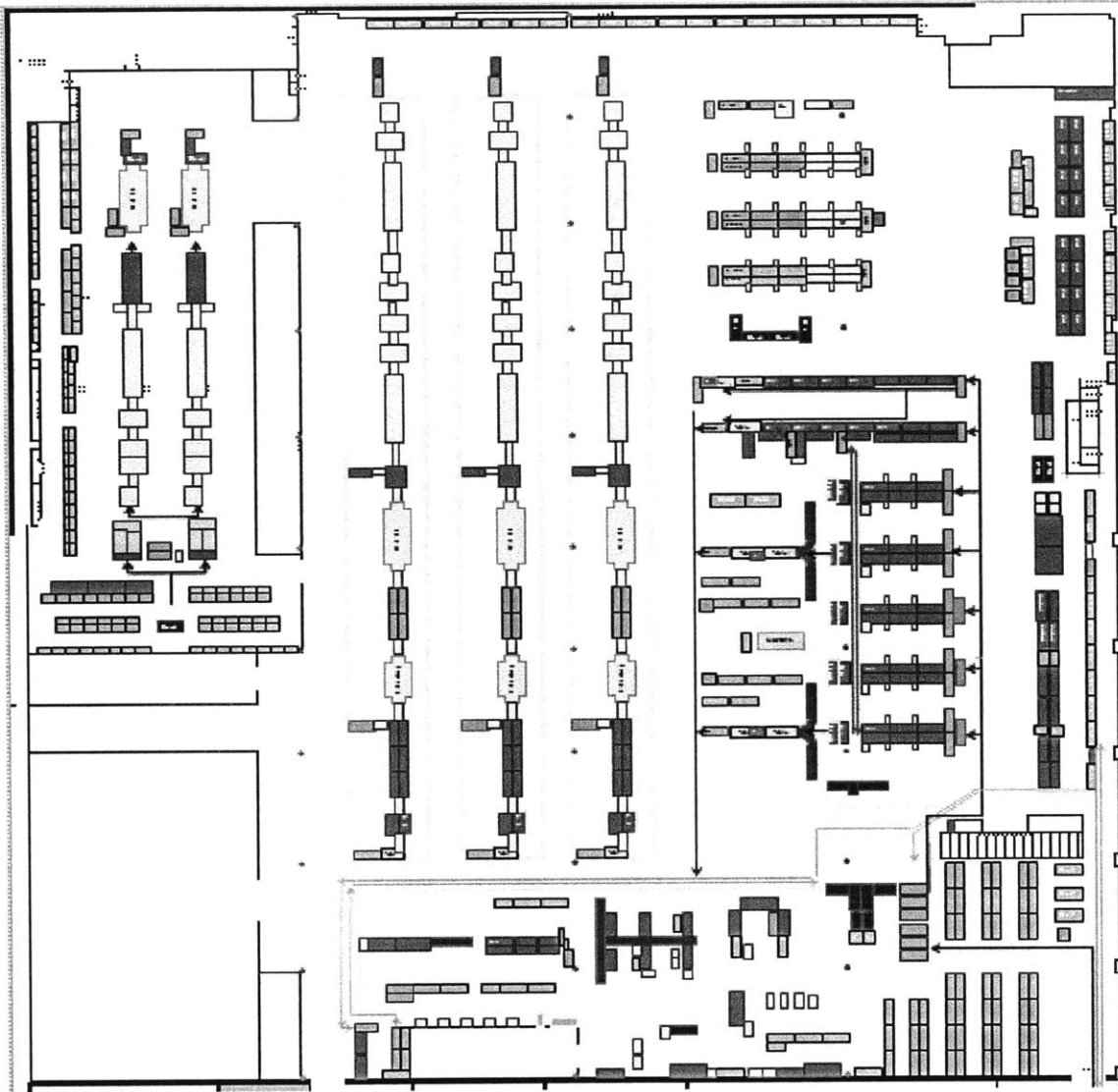


Figure 51: 12 Month Milestone – Stage 2

Figure 52 shows a crucial step; the final logistical move of the original “cell” sections of the factory. The remaining pick and place machines, ovens, and solder touch up benches are turned 90 degrees and integrated into the legacy assembly lines. The sub assembly benches are moved to the upper right corner of the factory. The test and troubleshooting benches in the top right are moved to where the older ovens and wave solder were located.

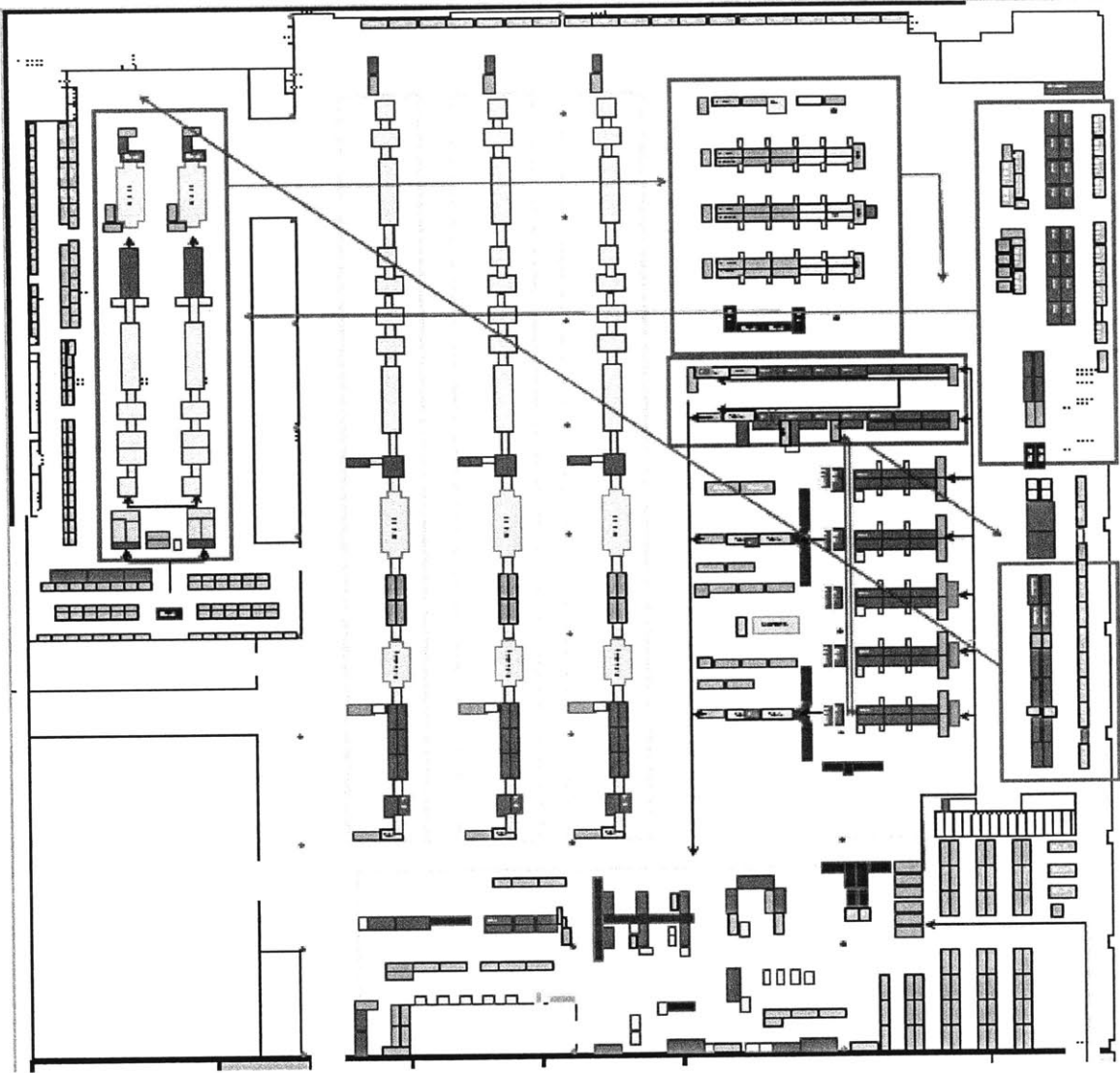


Figure 52: 12 Month Milestone – Stage 3

After these moves, all of the manufacturing lines now run from the front to the back of the factory. Figure 53 shows three modern lines are in place, the original lines have been streamlined, and many of the steps have been integrated - eliminating WIP and greatly reducing the amount of material flow, non-value added work, and the excess handling of parts.

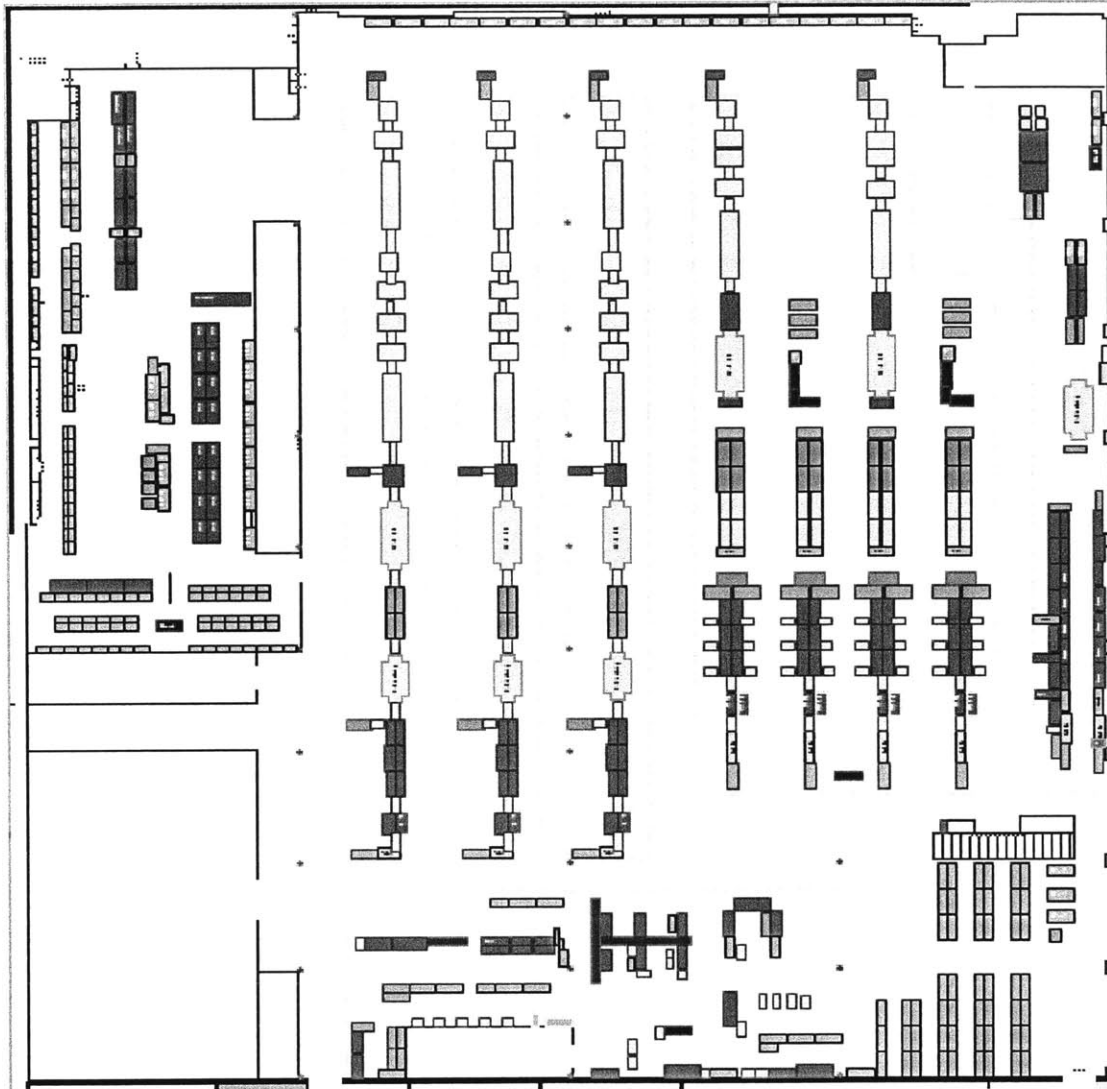


Figure 53: 12 Month Milestone – Stage 4

#### **7.4.1 Recommendations for the 12 Month Milestone**

There are multiple steps within this milestone, and these steps are perhaps the most critical steps to turn the factory into its final transformation. Transitioning these cells to their new locations will require advanced planning and because the factory already has new lines installed at this point. Navigating materials and equipment to their new locations must be done around the new lines as they will continue to run during this move. Ideally, all of these portions can be relocated to their new locations if the entire move were performed on a weekend. However, full manpower of labor, technicians, engineering, and management will need to be incorporated so that the transformation can be completed without interrupting production, and to ensure that all moved components are properly relocated, wired, and grounded, as safety is a key component in this entire process.

Other extremely important benefits of this set up are improved visibility across the plant floor, better communication, and improved safety within the factory.



## 7.5 Future State - 15 Month Milestone

Figure 54 shows the result of the 12 month milestone is three new production lines for next generation products and the production lines of legacy products streamlined and realigned to make better use of the factory.

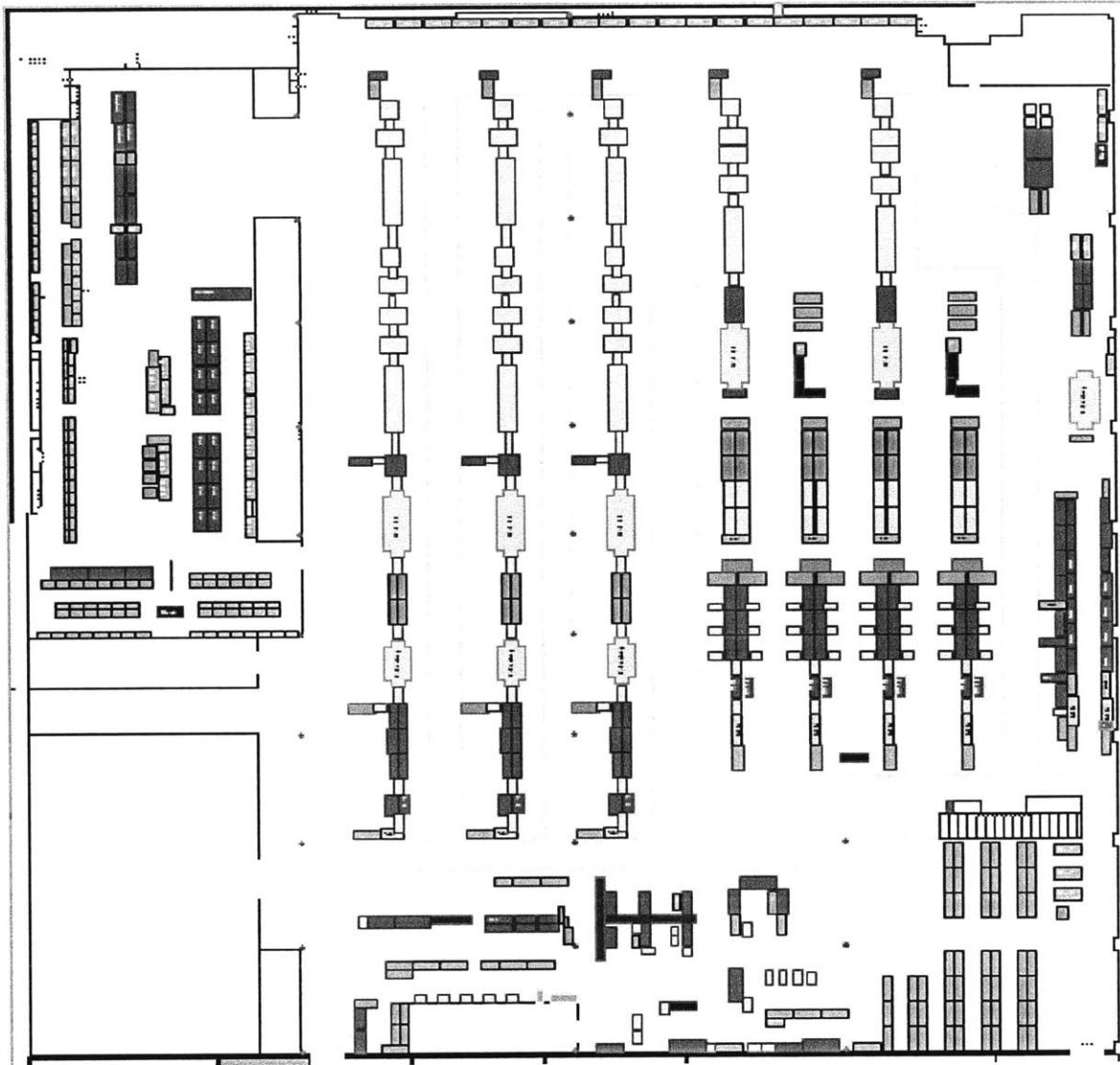


Figure 54: 15 Month Milestone – Stage 1

The final step, shown in Figure 55, would be to reduce the amount of assembly lines for legacy product as demand for these products diminishes and products are phased out and/or replaced by NextGen products. As this occurs, the old assembly lines are already situated in such a way that additional next generation lines can take their place. Five NextGen lines are shown in this final step.

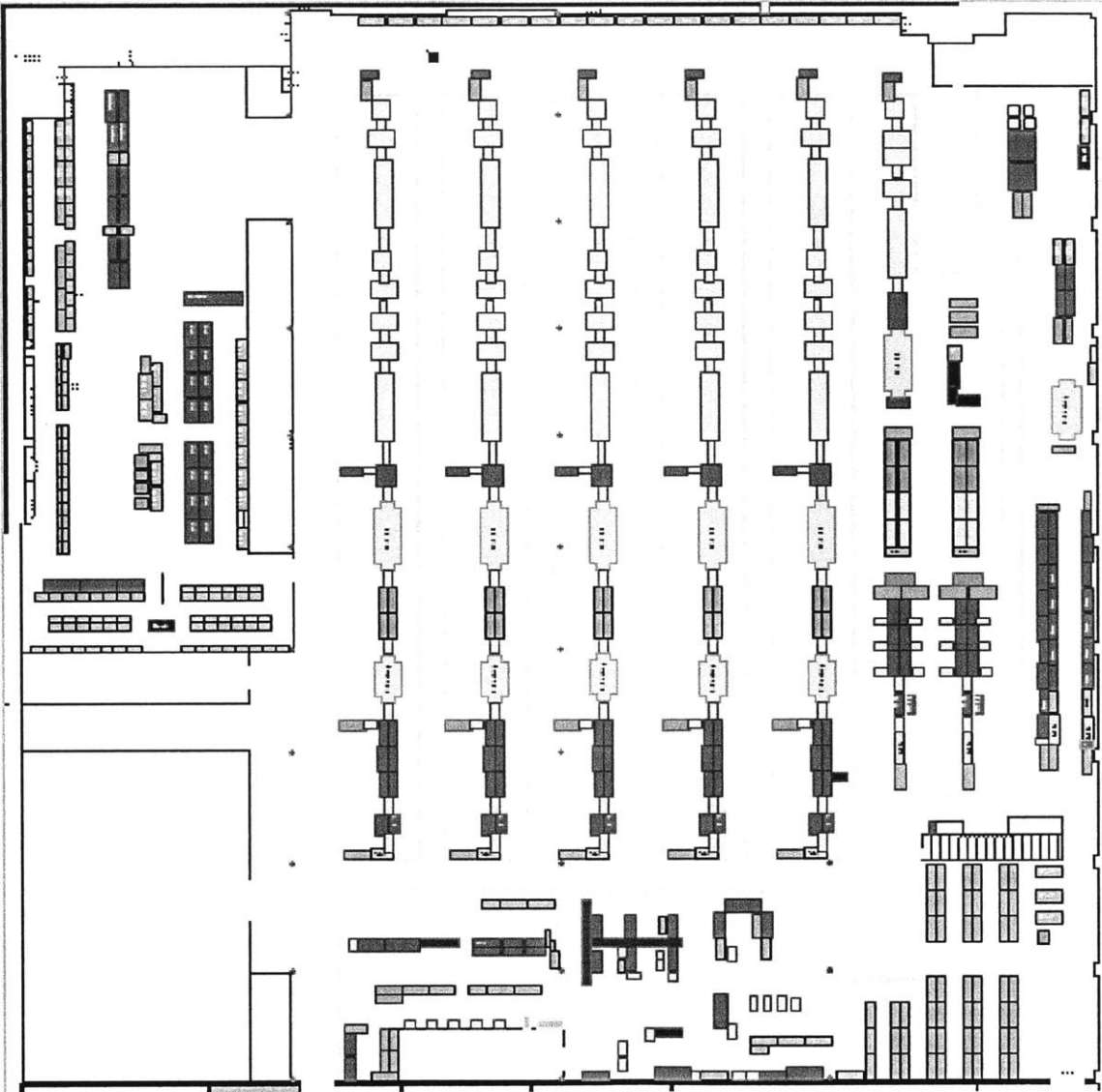


Figure 55: 15 Month Milestone – Stage 2

## 8. Conclusions

The result of the 12~15 milestone shows a minimum of three, and up to five new lines incorporated into the factory, with the rest of the original equipment and machinery re-organized to create an efficient production facility with very little WIP, reduced non-value added work, and a higher yield of products. A more organized plant allows more visibility and communication during the assembly process and therefore creates an environment where mistakes and problems are identified and resolved immediately.

Original state - factory runs a full first shift, and a partial second shift (~ 20% the staff size of first shift) with an output of about 150,000 servo drives per year.

New factory layout has 3 to 5 new lines for next generation products while still producing about 70% of legacy product (estimated 30 % decline in legacy product demand after new generation products are being produced).

- Each NextGen line adds approximate capacity of 1250 drives / week / shift
- 3 lines add ~200000 additional drive manufacturing capacity / year / shift
- With current full first shift and partial second shift
  - Old layout produces ~ 150,000 drives / year
  - New layout (with three new lines) produces ~ 450,000 drives / year
- 5 lines added produce about 1 million drives / year - operating on all three shifts
- Legacy lines still operating ~ 70% capacity
- Operating in three full time shifts, 5 days a week, this new factory layout has the space and capability to produce 1.5 million drives per year if five new lines are installed and the legacy lines produce about 70 percent of existing production. This is only possible by streamlining the current operations and optimizing the material and process flow in the current facility.
- The facilities peak capacity, if weekends are utilized, reaches 2 million total units per year. These estimates take in to account mean time to fail and mean time to repair rates [2].

This plan increases manufacturing capacity without having to construct an entire new facility, increases the throughput of the current product, and greatly reduces the amount of non-value added work in the original manufacturing process. Finally, this plan increases communication and visibility on the plant floor; improving both the culture and safety in the facility.

Although the reconfigured floor space allows a very large increase in manufacturing output in the same building that the company occupies, the warehouse and shipping area would need the same analysis and reconfiguration performed to handle the increase of both incoming and outgoing materials and products.

## Works Cited

- [1] D. McCalib, "Design Method of a Modular Electronic Printed Circuit board Testing System," MIT , Cambridge Ma, 2013.
- [2] V. Phadnis, "Production Line Design and System Analysis for New Product Introduction in Electronics Manufacturing" MIT, Cambridge Ma, 2013
- [3] E. H. K. Eikenr, The Business of New Product Development, Charlottesville , Va: University of Virginia Press, 2011.
- [4] S. S. Serpoe Kalpakjian, Manufacturing processes for Engineering, Upper Sadle River: Peason, 2008.
- [5] C. H. Fine, Clockspeed, Cambridge, MA: Basic Books, 1998.
- [6] M. Baudin, Lean Assembly, New York, NY: Productivity Press, 2002.
- [7] J. Liker, The Toyota Way, New York, NY: McGraw Hill, 2010.
- [8] *Leading Change: Why Transformation Efforts Fail*, 2007.
- [9] *Developing the Strategy, Vision, Value Gaps, and Analysis*, 2008.
- [10] *Cultural Intelligence*, 2004.

