Production Lead Time Reduction in a Semiconductor Capital Equipment Manufacturing Plant through Optimized Testing Protocols

by

Anubha Singh Bhadauria
Bachelor of Technology in Production Engineering
National Institute of Technology, Tiruchirappalli, 2011

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Signature redacted

Anubha Singh Bhadauria
Department of Mechanical Engineering
August 15, 2014

Signature redacted

Stephen C. Graves
Abraham Siegel Professor of Management Sciences
Thesis Supervisor

Signature redacted

David E. Hardt
Ralph E. and Eloise F. Cross Professor of Mechanical Engineering
Chairman, Committee for Graduate Student
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Anubha Singh Bhadauria

Abstract

Processes at a semiconductor equipment manufacturing facility were studied with the goal to reduce the production lead time. Based on the principles of lean manufacturing, DMAIC methodology was used to guide the process. Value Stream Mapping (VSM) of the whole process was done to determine that the Universal End Station (UES) was the module with the longest lead time.

This work focuses on the optimization of the testing process on the UES. Time studies were conducted for the assembly and test of the UES module and analysis of results revealed a testing process that is serial and thus of a very long duration. Further investigations revealed that some of the processes required the test technician to do manual calibrations and measurements which resulted in long test times.

Based on the interviews with involved personnel, historical data analysis and the research carried out, specific tests were recommended for automated testing and parallel testing. A decision tree was developed to help aid in the selection of the suitable candidates for automation while a dependency network diagram was developed to aid in selection of candidates for parallel testing.

It is projected that these recommendations will reduce the Testing lead time of UES by 8.4% and labor hours by 16.3%.

Keywords: Lean manufacturing, semiconductor, optimization, bottle neck, lead time, DMAIC, Value Stream Mapping, Time study, Root cause analysis.

Thesis Supervisor: Stephen C. Graves
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Chapter: 1

1. Introduction

This section provides an overview of the semiconductor industry as a whole and Varian Semiconductor Equipment and Associates (VSEA) background and its place in the chain. It goes on to describe the various products and tools offered by VSEA, their general machine architecture and the detailed architecture of the Universal End Station (UES) module which is the focus of the project. This work is part of a team project on how to reduce the production lead time of the UES. The specific focus of this thesis is on improving the testing process so as to reduce the production lead time.

1.1. Semiconductor Industry Overview

The semiconductor industry can be divided into two major segments: microchip manufacturers and capital equipment manufacturers. Microchip manufacturers are companies like Intel, Samsung and Taiwan Semiconductors that fabricate integrated circuits in manufacturing facilities called “fabs”. Each fab may have several pieces of equipment for various steps in the manufacturing process like ion implantation, chemical vapor deposition, etching etc. Capital equipment manufacturers are companies like Applied Materials, KLA-Tencor, and Lam Research Corp; that make high value machine tools for the fabrication process.

The capital equipment segment can be further divided based on the process for which the machine tool is used. Front End of the Line (FEOL) tools are used to create circuit elements that are on the device layer such as resistors, transistors, and capacitors. Back End of the Line (BEOL) machines are used to create the interconnecting layers of the chip. Varian designs and manufactures machine tools for ion implantation, which is a FEOL process.

It is also worth noting that the chip manufacturing side of the business is mostly concentrated in the hands of a few big firms. Thus, it is imperative for the sellers like VSEA to be highly flexible in terms of custom options and features offered as well as logistic demands of the customers to be able to retain their buyers.
1.2. VSEA Background

Varian Associates was founded in 1948 in California. The company's early years focused on the development of klystrons, linear particle accelerators, and instrumentation equipment [1]. In 1968 Varian Associates acquired Extrion Corporation in Gloucester, MA, a manufacturer of medium current ion implantation machines. Varian Semiconductor Equipment Associates Inc. was spun out of Varian Associates in 1999 [2]. VSEA was acquired by Applied, which is a market leader in semiconductor industry, in November 2011 [2].

The Varian facility at Gloucester specializes in manufacture of ion implantation machines that comprise one of the multiple steps needed for fabrication of chips. Varian also has its own R&D facility for in-house design of these tools. The tools are designed, assembled and then tested at the facility.

1.2.1. VSEA Product Line

Varian currently offers five machine types under the VISta machine platform as summarized in Figure:1- Medium Current, High Current, High Energy, Ultra High Dose, and Solion.

Medium Current, High Current, and High Energy systems share identical machine architecture as they all use an ion beam that is focused using electromagnets for implantation. Each machine type is used for different types of implants, depending on the transistor requirements. In 2009, Medium Current, High Current, and High Energy comprised 28%, 46 %, and 15% of the ion implantation market, respectively [3].

The High Current line includes the Trident, which is, currently the most modern and popular tool being manufactured at VSEA and has been considered for this project. It has several advanced features like better beam decontamination, cryogenic wafer cooling option [4] for better quality of implant.

Ultra High Dose machines have a unique process for ion implantation in which an ion cloud is used instead of a focused beam. This type has the lowest demand, comprising 12% of the ion implantation market in 2009 [3].
Solion is another ion implantation tool that is manufactured at the facility. It is used in solar cell manufacturing and has a completely different architecture as compared to the other machines under the VIISta platform. The Solion tool was not considered for this thesis.

1.2.2. Machine Architecture

Varian’s ion implantation machines are comprised of five modules that can be assembled and tested in parallel: analyzer, corrector, facilities and gas box, Universal End Station and Equipment Front End Module. Each module consists of several complex electromechanical subassemblies. Figure 2 provides a schematic of the machine.

Some of the sub-modules also have “selects” and “options” that are customized by the buyer’s demand. The “selects” refer to the list of features out of which at least one has to be selected for the machine to function while “options” refer to completely separate features that may or may not be included in the machine based on the customer requirement. Example: the type of cryo pump to be installed is a select while the wafer arm viewing pane is an option.

The individual modules are assembled and tested separately and then packaged and shipped to the customer location where they are put together to form the whole machine. The company previously assembled all the modules together to test the machine tool as a whole before disassembling again for the ease of shipping. But, this practice has been abandoned after historical analysis of the quality data which indicated that the current practices were reliable.

Figure 1: VIISta product line
enough to forego the final full testing completely. This has resulted in the reduction of the lead time from 17 days to 11 days.

Figure 2: Schematic of ion implanter

The main modules are described below:

1. The **Analyzer module** consists of the 90 degrees electromagnet. This module acts as an analyzer that ensures that the beam has the required characteristics before it hits the wafer to ensure the right concentration of doping on the wafer. The current lead times for the assembly and testing of this module are 24 and 23 hours, respectively.

2. The **Corrector module** consists of 55 degrees or 70 degrees electromagnet depending on the tool type. They are used to cleanse, focus and steer the ion beam generated in the source module. The current lead times for assembly and testing of this module are 14 and 10 hours, respectively.

3. The **Facilities and gas box module/Source module** contains the facilities connections for the implanter, the Gas Box and the ionizing cathode. A heated cathode is used to ionize the dopant gases like Boron Tetra Fluoride or Arsine. The current assembly and testing lead times are 28 hours and 15 hours respectively.
4. **The Universal End Station module** interfaces with the Beam Line module and consists of a wafer handling system with many moving parts that carry the wafer, making it one of the most complex assemblies. The current lead times for assembly and testing of the UES module are 5.4 and 5 days, respectively which make it the bottle neck in the process. Figure 3 provides a schematic of the UES.

5. **The Equipment Front End Module (EFEM)** comes pre-assembled from the vendor and is directly integrated into the UES without any work at the facility.

![Figure 3: Universal End Station schematic [5]](image)

1.2.3. **Universal End Station**

One of the major functions of the UES is to bring new wafers into a vacuum environment where the ion implant is performed. The UES receives wafers from the EFEM’s transfer robot; this robot exchanges wafers from the loadports to a cassette in the UES load locks. The load locks are filled with wafers at atmospheric pressure, are pumped down to vacuum, then release the wafers to the vacuum robots.

The second major function of the UES is to perform the ion implant on the wafer by passing the wafer through the ion beam. This is accomplished with the vacuum robots, the orienter, and the platen. The vacuum robots pass a wafer to the orienter for rotational positioning, and then
move the wafer from the orieniter to the platen. The platen then passes the wafer through the ion beam to perform the implant. The vacuum robot then returns the wafer from the platen to the load lock, and the process repeats until all of the wafers in a load lock have been processed. The load lock then pressurizes, and exchanges the processed wafers for new wafers via the transfer robot.

The entire wafer handling process is choreographed to provide maximum throughput. The system can operate at rates of up to 500 wafers per hour.

UES Architecture

The Universal End Station consists of 6 sub-modules: the Frame, Top Process Chamber, Bottom Process Chamber, Wafer Handler, Electronics Control Rack, and Tool Control Rack. These sub-modules are assembled independently and then integrated to form the complete UES module. After integration, the UES module is put through a series of functional tests for qualification.

The UES module is made up of the following sub-modules:

Frame: The weldment frame forms the base of the UES module onto which the remaining sub-modules are mounted. The frame is a High Level Assembly (HLA) that is outsourced to an external supplier. It comes with all of the harnessing; however, some re-routing is required.

Top Process Chamber: The Top Process Chamber houses the cryo pumps (two for Trident and three in other models) that are required to create high vacuum in the process chamber. The top process chamber also houses gate valves that are used to regulate the cryo pumps.

Bottom Chamber: The bottom process chamber houses the rotating platen (roplat). The roplat is mounted to the tilter assembly that provides X-axis movement to adjust the implant angle. The tilter and the platen are mounted on an air bearing that provides for Y-axis movement and provides functionality for incident angle correction and multiple angle implants [5]. The wafer is secured to the platen through electro-static clamping.

Wafer Handler: The wafer handler has three major components: the load locks, robotic arms, and the orieniter. The left and right load locks are used to hold wafers. Each load lock contains a wafer cassette platform which holds up to 25 wafers, wafer mapping lasers to detect the location of wafers in the cassette, an elevator drive to move the cassette through the laser
beam for wafer mapping, a load lock isolation valve to separate the load locks from the high vacuum area of the wafer handler, and a turbo pump to create vacuum in the load locks. The robotic arms are used to move individual wafers from the cassette in the load lock to the orienter, then from the orienter to the platen for implant, and then back to the cassette after implantation. The robot arms are driven by theta and radial motors with optical encoders for precise and repeatable positioning. The purpose of the orienter is to determine wafer eccentricity and notch position. The orienter then re-positions the notch so that the crystal orientation of the wafer matches the implant recipe. The orienter uses LEDs to establish the rotational position of the notch.

**Electronics Rack:** The chassis of the electronics rack is supplied with the Frame HLA. It is then removed from the frame and assembled separately. It houses special power supplies and ADIOs.

**Tool Control Rack:** The tool control rack houses specific control computers and control modules for the process chamber and wafer handler.

### 1.3. UES Production Process Overview

For obtaining an overview of the whole production process and determining the problem areas, the entire process flow was studied and a Value Stream map was developed.

Keller[6] defines value stream as the steps taken to deliver the specific product or service. Value stream mapping is a tool that helps to see and understand the flow of material and information as a product or service makes its way through the value stream [7]. The objective of creating a value stream map is identifying every action required to design, order and make a specific product and sorting it into three categories:

1. Those which actually create value as perceived by the customer;
2. Those which create no value but are currently required by the product development, order filling or production systems (type one muda) and so can't be eliminated just yet; and
3. Those actions which don't create value as perceived by the customer (type two muda) and so can be eliminated immediately. [7]
A value stream map is a lean tool that takes into account not only the activity of the product, but the management and information systems that support the production process. Thus, it gives insight into the production process as a whole which is especially helpful when working to reduce the cycle time.

Following the DMAIC (Define, Measure, Analyze, Implement, Control) methodology, described in detail in Section 2.3, the entire value stream map for the UES Production process as shown in Figure: 4 was mapped out as the first step.
1.3.1. Production Scheduling

The lead time of the UES module is measured from the time that the module is laid down to the time it takes to complete testing. The production schedule is driven by the MRP system, and it back-calculates a scheduled lay down date based on the shipping date. However, it is fairly common for the customers to alter their orders a few days before shipping date, thus, upsetting the whole schedule. The production supervisor makes the day-to-day decision about the scheduling of builds and resource allocation manually, based on the latest.

Production takes place in four shifts. On weekdays there are two 8.5 hour shifts and one 10.5-hour shift. On weekends there is one 12-hour shift. Each shift has a production supervisor, assemblers, and test technicians. There is a half-hour overlap between shifts for handover. The work-force is a mix of full-time workers and contractors with different skill levels on different tasks.

Due to the high variability in demand of the product, the company prefers to have its assemblers and technicians cross-trained and capable of working across different sub-modules and modules. For example, within the UES cell an assembler can work on any of the sub-modules- Top Chamber, Bottom Chamber, Wafer Handler, Frame etc. They can also work on assembly of the Beam Line, which is a separate module. While this structure benefits the company by enabling them to maintain a smaller work force and offering flexibility, it also makes resource planning and scheduling challenging.

Each machine is built based on a Production Build Order (PBO) which specifies the exact configuration options requested by the customer. A PBO can be changed upon customer request up to 10 days before the ship date and such changes are very common.

1.3.2. Assembly and Test

UES production is divided into three phases: assembly, integration, and testing. In the assembly phase the six sub-modules (HLA Frame, Top Chamber, Bottom Chamber, Wafer Handler, ECR, and TCR) are assembled in parallel, typically with one assembler working on one sub-module. The average time for each sub-module assembly is shown in Table 2. This is followed by integration, where the assemblies are mounted onto the frame and integrated with each other.
electrically and mechanically. Integration is performed by one or two assemblers, depending on their availability and workload, and takes approximately 75 hrs. Integration is followed by testing, where the module is put through a series of functional tests. This process takes approximately 50 hours. The average lead time for the assembly and testing of the UES is currently 11 days. After testing, the UES module is sent for packaging and crating. The 5 different modules are packaged and shipped separately; this method of shipping is called ‘Smart Ship’.

<table>
<thead>
<tr>
<th></th>
<th>Time (man-hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly</td>
<td>75</td>
</tr>
<tr>
<td>Integration</td>
<td>75</td>
</tr>
<tr>
<td>Testing</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 1: Break down of UES Lead Time

<table>
<thead>
<tr>
<th>Sub-module</th>
<th>Assembly Time (man-hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame</td>
<td>4</td>
</tr>
<tr>
<td>Top Process Chamber</td>
<td>8</td>
</tr>
<tr>
<td>Bottom Process Chamber</td>
<td>4</td>
</tr>
<tr>
<td>Wafer Handler</td>
<td>15</td>
</tr>
<tr>
<td>ECR</td>
<td>7</td>
</tr>
<tr>
<td>TCR</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 2: Assembly Time Break-down by Sub-module

The UES line functions as a flow line. It has designated areas for assembly, integration, and testing. There are two assembly bays each for the Top Chamber, Bottom Chamber, and Wafer Handler; three bays for Integration, which are also used for the frame lay-down preparation, and build-up; and eight bays for testing. See Figure 5.
1.3.3. Material Inventory

The raw material inventory for production can be divided into five categories: Supplier-managed Inventory, Warehouse Inventory, Supermarket Inventory, Gold-Square Inventory and In-line Inventory. These inventories are managed through an MRP system, which calculates the inventory levels through forecasted demand and supplier lead-time. The delivery of these parts is also coordinated through the same system, using scheduled ship dates, lay-down dates, and production lead-time estimates.

Supplier-managed Inventory is the inventory of parts that are delivered directly from the supplier to the shop floor. The supplier-managed inventory is managed through a supplier kanban and includes complex HLA's such as the Frame, castings for the top chamber, bottom chamber, and wafer handler, and TCR. Suppliers for these parts are mostly local and have a turn-around time of around 2 days. The delivery of these parts is scheduled through MRP, but
the production supervisor can also directly place an order for these parts with the supplier in case of an emergency.

Warehouse Inventory is parts that are stored at the warehouse (Building 80) on the VSEA campus. These include small parts that are required on a daily basis at the Supermarket or the assembly lines. Parts required from the warehouse are pulled 24 hours before the laydown using Z-pick codes.

Supermarket Inventory is inventory of the sub-assemblies built in the Supermarket. These sub-assemblies get assembled into the sub-modules. The demand for these parts is driven by shop orders that are issued five days before the laydown date. The supermarket is fed by the warehouse and also through direct deliveries from the suppliers. The supermarket in-turn feeds the gold-squares.

Gold Square Inventory is the inventory of parts that are made-to-stock by the Supermarket. These are typically high volume- fast moving parts and are stored in the assembly area on special racks called Gold Squares. This inventory is controlled through a kanban.

In-line Inventory is the inventory of parts that are stored at the assembly line. These include parts like screws, washers, nuts, O-rings, harnesses etc. The warehouse feeds this inventory.
Chapter: 2

2. Preliminary analysis and hypothesis tree

2.1. Motivation

Varian has been engaged in lean manufacturing initiatives since 2004, with lead time reduction being a focal point of lean projects. Lowering lead times allows for less Work in Process (WIP) and a higher response level to last minute changes in PBO.

Lowering WIP allows for less money to be tied up in in-process inventory, reduces storage requirements, and mitigates the risk of obsolescence. Ion implant machines are high in cost, and are physically large, thus the benefits of reduced WIP are of high value to Varian.

Varian also experiences frequent client requested changes to PBOs. Varian allows clients to change the specifications of a machine at any time during production, or cancel the order entirely, without penalty. Shortening the lead times will mitigate the risks associated with PBO changes by allowing the tool to be produced as close to the ship date as possible.

The ion implant tool is comprised of three modules that are built in parallel at the Gloucester facility, with a fourth module supplied by a vendor. Currently, the lead time for the UES is the longest of the modules at 10.9 days for the Trident machine, whereas the lead times for the Source and Beam Line modules are currently 2 days each. Varian is interested in reducing the lead time of the UES, as it will directly reduce the overall lead time of the tool.

2.2. Problem Identification

Through preliminary analysis that included interviews with department managers and shift leads, and first person observations, a hypothesis tree was developed as shown in Fig: 6. The process was broadly divided into Assembly and Testing and various issues which negatively influence the lead time were identified, namely: rework, redundant testing, workforce scheduling etc.
Three major areas with the highest potential for improvement were selected: workforce scheduling, materials management, testing protocols.

**Workforce Scheduling**

The average lead time from year-to-year is documented and used to determine a target lead time for the subsequent year; however, the theoretical minimum lead time for the assembly of the UES is currently not known. The identification of the critical assembly and test sequences that provide for the shortest lead time can be used to develop a production plan that drives the prioritization of work being performed on each machine. This will allow for the assembly efforts to be focused on tasks that work towards keeping the lead time of the UES minimized.
The critical assembly sequences will generate a priority hierarchy for future lean production initiatives; the processes that lie on the critical path should have priority for lean projects over processes that are not on the critical path. These high priority processes can be analyzed for value added and non-value added activities; non-value added steps should be minimized. Reducing the time of a critical path process will directly reduce the overall lead time of the UES by an equal amount.

VSEA currently operates four shifts for the UES flowline, shown below in Table 3.

<table>
<thead>
<tr>
<th>Shift Number</th>
<th>Days (Hours)</th>
<th>Number of Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Monday – Friday (7am – 3:30pm)</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Monday – Friday (3pm – 11:30 pm)</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Monday – Thursday (9pm – 7:30am)</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>One weekday plus Saturday &amp; Sunday (7am – 7pm)</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 3: Shift structure for UES assembly

Employees are assigned by the shift’s supervisor to work on a machine at the beginning of a shift. The specific work that an employee performs on a machine, however, is not well defined. Typically employees will either continue a procedure that was started on a prior shift, will select a procedure based on their own diagnosis of priority, or will select a procedure based on their own personal preference. Developing a work-plan for each shift will ensure that the work is constantly focused on the critical lead time items. Also, there are no milestones set up for a particular shift or labor which leads to unequal division of workload across shifts.

Material Management

Material issues contribute significantly to increasing the UES lead times. There are two main reasons for these issues: material shortages and material quality issues.

Material shortages are shortages on parts that are received at the assembly line from the supplier, the warehouse, or the super-market. The main reason for these shortages is variability in demand and frequently changing PBOs and lay-down schedules.
Material Quality Issues arise due to parts from the supplier or supermarket not meeting quality or design specifications and often result in time wasted in rework, purging (returning the part back to the supplier), and waiting on replacement parts to be issued.

Reducing material shortages and reducing the quality issues will help reduce the overall lead time.

Testing protocols

A critical path analysis for testing can be done similar to assembly. This will generate a set of steps which lie on the critical path and need to be shortened to reduce the lead time. Also, testing seems to be a highly sequential process and requires a lot of input from the operator. Possibility of automation and parallel testing would be another area to be looked into.

After careful consideration and several meetings with the Manager, the team decided to split the process into two phases: Assembly and Testing and work on lead time reduction in both areas. Three areas were further identified for individual work:

1) Reduction in lead time of UES by reducing blockage through optimized worker scheduling.
2) Reduction in lead time of UES by reducing starvation by Kitting of warehouse supplied parts.
3) Reduction in lead time of UES by reducing the rework and redundancy in test phase of UES.

My teammates Blake Sedore and Sonam Jain, worked on the first two respectively; my work revolves around the lead time reduction of the Test phase of UES.

2.3. Approach

The team used the DMAIC (Define, Measure, Analyze, Improve, and Control) methodology to approach this problem. DMAIC is a lean methodology used to improve, optimize, and stabilize processes and is widely used in the industry.
The process of addressing the problem at hand will be divided into the following discrete ordered steps:

**Define:** In this step the problem, goal, resources, project scope, and the time-line will be articulated and captured in a project charter.

**Measure:** The purpose of this step is to establish a baseline to form the basis for improvement. In this step data will be collected and performance metric baselines will be established. Pareto Charts, Process Flow Maps, Value Stream Maps, and Time Studies will be used to gather and document data.

**Analyze:** In this step the data that is collected in the Measure step will be thoroughly analyzed. Potential areas for improvement and root causes of problems will be identified. Tools such as Ishikawa diagrams, 5 Whys, and Design of Experiments (DOE) will be used.

**Improve:** In this step solutions to the problem will be identified, tested, and deployed. Tools like Plan-Do-Check-Act (PDCA) and FMEA will be used.

**Control:** The purpose of this step is to implement steps to sustain the proposed improvements. This includes creating and updating documents and business systems.
Lean Six Sigma: DMAIC

- **DEFINE**
  - Define the problem.

- **MEASURE**
  - Map out the current process.

- **ANALYZE**
  - Identify the cause of the problem.

- **IMPROVE**
  - Implement and verify the solution.

- **CONTROL**
  - Maintain the solution.

Figure 8: DMAIC methodology [9]
Chapter: 3

3. Assembly and Testing time studies of the UES

The ASME Industrial Engineering standards [10] define time study as "a work measurement technique consisting of careful time measurement of the task with a time measuring instrument, adjusted for any observed variance from normal effort or pace and to allow adequate time for such items as foreign elements, unavoidable or machine delays, rest to overcome fatigue, and personal needs."

Groover[8] further explains that it involves a direct and continuous observation of a task, using a timekeeping device (e.g., decimal minute stopwatch, computer-assisted electronic stopwatch, and videotape camera) to record the time taken to accomplish a task and it is often used when:

- There are repetitive work cycles of short to long duration,
- Wide variety of dissimilar work is performed, or
- Process control elements constitute a part of the cycle.

3.1. Objectives

For our project, the assembly and testing time studies were conducted with the following goals in mind:

- To study and understand the whole process.
- To track time for each task in the process and establish approximate standard times under ideal conditions.
- To identify and segregate Value added and Non-Value added processes and corresponding times.
- To look for potential areas for improvement.

3.2. Methodology

The machine chosen for time studies was the model “Trident” which is the most popular machine and makes around 70% of the total production volume. The completely assembly (116
labor hours) and testing (72 labor hours) was followed by the members of the team by working round the clock in shifts.

For the purposes of data collection a naming denomination system was set up in accordance with Lotus Notes database as shown in Figure: 9. The machine consists of individual blocks called modules, that are shipped separately and then assembled at the customer’s fab. The smaller building blocks within these modules are called sub-modules and are labelled A1 through A21 for assembly; and T1 through T61 for testing. These sub-mods have steps and instructions listed for each procedure which are further named A1.01, A1.02 etc. as shown in the Figure: 9.

Figure 9: Naming denomination in accordance with Lotus notes [12]

The end and start times for each task were individually recorded and categorized into the following subheads:

- Value Added Time (VA)
- Non-Value Added Time (NVA)
Table 4: Types of VA and NVA processes

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Process</th>
<th>Acronym</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Value Added</td>
<td>VA</td>
<td>Time for those work elements that transform the product in a way the customer is willing to pay for.</td>
<td>Time spent in installing a part like pump</td>
</tr>
<tr>
<td>2</td>
<td>Non value added process</td>
<td>NVA-P</td>
<td>Time for those elements that are a part of the process and have to be done to complete it but add no value to it.</td>
<td>Time spent in unpackaging material</td>
</tr>
<tr>
<td>3</td>
<td>Non value added movement</td>
<td>NVA-M</td>
<td>Time for those elements that involve moving a sub assembly or a part.</td>
<td>Time in moving subassemblies over to the integration bay</td>
</tr>
<tr>
<td>4</td>
<td>Non value added waiting</td>
<td>NVA-W</td>
<td>Time spent in waiting due to reasons like part shortage etc. while the labor is available to work on the machine.</td>
<td>Waiting time due to material shortage</td>
</tr>
<tr>
<td>5</td>
<td>Non value added idle</td>
<td>NVA-I</td>
<td>Time spent during the periods when the machine is idle as there is no labor available to work on it.</td>
<td>Idle time during scheduled breaks</td>
</tr>
</tbody>
</table>
The NVA time was further divided into four subheads:

1. Non- Value Added Process (NVA-P)
2. Non- Value Added Movement (NVA-M)
3. Non- Value Added Waiting (NVA-W)
4. Non- Value Added Idle Time (NVA-I)

These are described in the Table: 4. The data was recorded in the format shown in Figure: 10.

<table>
<thead>
<tr>
<th>People</th>
<th>Date/Time</th>
<th>Task</th>
<th>Description &amp; Suggestions</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3232014 11:24</td>
<td>2</td>
<td>Attaching fitting hardware to valve handle</td>
<td>NVA-P</td>
</tr>
<tr>
<td>1</td>
<td>3232014 11:26</td>
<td>2</td>
<td>Prepping o-rings for valve handle and installing o-rings</td>
<td>VA</td>
</tr>
</tbody>
</table>

Figure 10: A sample data sheet for assembly time record

3.3. Assembly time study results

The total assembly of the UES module took around 5.8 days. Assembly of different sub mods can be done in parallel depending on their precedence and labor availability. Figure: 11 shows the active and inactive periods observed during the assembly time studies. The active periods shown in green indicate the time when that particular sub module was being worked on by at least one laborer. The periods marked with grey indicate the inactive time when the sub mod was just sitting idle due to labor shortage, part shortage etc. The combined grey and green lines show the total time from the start to the end of the sub module assembly. We observe from this Gantt chart that the inactive time per module makes up a significant portion of the total time.
Figure 11: Assembly of UES: Gantt Chart

Figure 12: (a) Assembly of sub mods: active and inactive (b) further subdivision of active time (c) further subdivision of inactive time

Figure 12(a) represents the percentage active and inactive time of all the submodules combined together. We note that the inactive time here is therefore not equal to the total inactive time on the grand state of the machine as a whole but a summation of the individual inactive times of submodules. For example: there may be instances when a few submodules are inactive while at least one submodule is active. In such cases, the machine as a whole is active.
The green or active portion from Figure:12(a) has been further classified as VA, NVA-P, NVA-M in Figure:12(b). This means that all the time when a laborer is involved with the module is marked as active(including the non value added process and movement steps). It shows that NVA-M forms only 2 percent of the total active time and can be overlooked.

Figure:12(c) is the further breakdown of the grey inactive portion of the Figure:12(a) and includes the waiting and idle times. The waiting time is only 3 percent i.e. it was only in very rare cases that the parts needed for an assembly were not available. The major cause of inactive time was the idle time i.e. unavailability of labor.

Figure:13 shows the“ grand state” of the machine as a whole i.e. the state is active whenever even one sub module is being worked on. The inactive periods include idle time and scheduled breaks taken by workers.

The grand active and inactive time is further shown as percentages in figure14(a) and (b). While figure 14(a) takes all time into account in continuation from start to end; figure14(b) omits the times when the factory was not available for work e.g. the Friday night shifts when the facility is
closed. We again observe that about 35% of the time the grand state of the machine is inactive indicating that it is not being worked on for long periods of time and just adding to the WIP.

![Pie chart showing active and inactive percentages](image)

Figure 14: (a) Grand state for assembly: active and inactive (b) Grand state: with unavailable factory time omitted.

### 3.4. Testing time study results

The entire testing cycle took about 5 days. As in the case of assembly, in Figure: 15, the blue colored bars indicate the active time while the grey indicates the inactive time. The red bar in the middle represents the amounts of time spend in ECO or the Engineering Change Order. This indicates a special engineering change that was made by the design team. This is a rare instance which may occur once in several years and is not indicative of a typical machine build; therefore, it will not be included for the purpose of our analysis. It can be observed that the inactive grey portions are very small as compared to the assembly Gantt chart in Fig.11. This is because most of the tests are a serial process and are done in sequence. We note that most of the testing process is currently carried out as a series of steps and very few tests are done in parallel.
Figure 15: Testing of UES: Gantt chart

Figure 16(a) represents the individual active and inactive time of all the submodules combined together. As in the case of assembly, the inactive time here is therefore not equal to the total inactive time on the grand state of the machine as a whole but a summation of the individual inactive times of submodules. From comparing Fig. 16(a) against Fig. 12(a), we see that the inactive time in testing is very small as compared to assembly.

Figure 16: (a) Testing of sub mods: active and inactive (b) further subdivision of active time (c) further subdivision of inactive time
The blue or active portion from figure:16(a) has been further classified as VA, NVA-P, NVA-M in Figure:16(b). Figure:16(c) is the further breakdown of the grey inactive portion of the Figure:16(a) and includes the waiting and idle times. We note that NVA-M and NVA-W, as a percent of total time are negligibly small here. Also, another fact is that NVA-P is 90 percent and form the major portion of the active time. The reason is that testing as a whole is considered to be a Non-Value added activity as it is not something that the customer would want to pay extra value for. So, all the time in testing other than major calibrations has been called NVA-P.

Figure:17 shows the” grand state” of the machine i.e. the state is active whenever even a single sub module is being worked on. The inactive periods include idle time and scheduled breaks taken by workers and off shifts when facility was closed. The grand state time begins from the start time of the first sub module and ends with the end time of the last sub module to be completed.

![Grand State of Machine During Testing](image)

Figure 17: Grand state of the machine during testing
The grand active and inactive time is further shown as percentages in Figure 18(a) and (b). While Figure 18(a) takes all time into account in continuation from start to end; Figure 18(b) omits the times when the factory was not available for work e.g. the Friday night shifts when the facility is closed.

![Pie charts showing active and inactive time](image)

Figure 18: a) Grand state for testing: active and inactive (b) Grand state: with unavailable factory time omitted.

### 3.5. Discussion

The results of the assembly and testing time studies helped identify three areas of improvement that could be individually worked on.

The results showed that the modules were inactive for very long periods which resulted in accumulation of excessive Work In Progress (WIP). This is a result of improper scheduling of workers and suboptimal distribution of work. Sedore’s thesis [12] focuses on this area by designing an optimal cyclical schedule.

We identified that a large amount of NVA time was spent in searching for parts through the bins or waiting for parts that were missing from the bins. Jain’s thesis will focus on improving this by kitting of the components that arrive from the warehouse.
The results of testing time studies clarified that the process was largely being done as a series of steps. As seen in Figure 15, hardly any steps overlap in parallel. Therefore, an opportunity to design a set of parallel test processes will be explored in this thesis.

Also, through various interviews with the test technicians and thorough study of the testing process, other paths for improvement have also been identified. One such area is simultaneous build and test or trying to push some tests to the preceding levels in the chain like supermarket or the vendor. Another would be the analysis of the Quality notifications over the years and identify the tests that are redundant in the sense that historically those parts never fail. This analysis may also lead to fruitful discoveries about some faulty components or methods that lead to very frequent failures and need improvement. These concerns are also addressed in this thesis in the following sections.

3.6. Summary

On the basis of time studies and numerous interviews conducted with Quality Engineers, test technicians, Manufacturing Engineers etc.; certain probable areas of improvement were identified. While Jain’s thesis focuses on assembly lead time reduction through improved kitting; Sedore’s thesis is focused on assembly lead-time reduction through workforce scheduling.

The area of testing will be addressed in this thesis and the following paths will be explored for reducing the testing lead-time of the UES through improved testing protocols:

- Automated Testing
- Parallel Testing
- Historical data analysis root cause analysis of frequent failure modes
- Push back to supermarket
- Redundancy Testing
- Simultaneous test and build
Chapter: 4

4. Testing Analysis

Based on the Testing time study, six paths were suggested for improving testing protocols; namely- automated testing, parallel testing, historical data analysis, push back to supermarket, redundancy testing and; simultaneous test & build. The following sections explore the methodology adopted to explore these areas further and the results obtained by each analysis.

4.1. Automated Testing

We propose that selective tests be automated. Many tests require some scalars and offsets to be entered manually as well as options on the screen to be clicked on manually. This requires the test technician to be physically present throughout the test to guide the system through every step. Also, this makes the test time longer as sometimes the technician has to check and make decisions based on the individual machine model.

An automation wizard will be designed to automatically check for all conditional and safety interlocks. The user will select the test from the drop down menu and click start. There will be minimum user interference.

4.1.1. Methodology

To select suitable candidates for automation, the decision tree shown in Fig: 19 was developed with the help of the Test Automation group.

The Varian Control System (VCS) is the governing software developed in-house by VSEA and is used as control software to operate the machine tools as well as for testing purposes. Tweaking the entire base VCS is a very time consuming process. Therefore, the test automation group at Varian uses additional software called LabVIEW developed by National Instruments for testing purposes alone. An additional template for tests is coded in LabVIEW and installed onto the VCS. After the final test, this auxiliary automation software can be uninstalled from the PCs before shipping it to the customer.
For selecting the best candidates for automation, the first step was to short list the tests that needed some sort of calibration or measurement that caused time delay. If a test needs calibration or measurements and has no routine for it in the Varian Control System (VCS), it was considered to be a good candidate for automation; whereas, if a routine is present in VCS then a value analysis was conducted to see if any value can be added by automating it. Also, if no calibration or measurement is involved but automation would reduce time or human error, then it was considered for automation. The final factor to be considered before going ahead with automation was the safety concerns involved.

All 63 UES tests were run through the decision tree shown in Fig: 19 one by one and the results are summarized in the following subsection.

![Automation routine decision tree](image)

**4.1.2. Results**

After running them through the automation routine decision tree, the following tests were found to be well suited for automation:

1. Burst tests
   a) Air bearing burst test
   b) Profiler burst test
c) Elevator burst test  
d) XP-VPS burst test  
e) Orienter burst test

2. Dual PFG calibration

Table: 5 shows the lead time reduction and labor hours saved by automating the selected tests.

Table 5: Time saved by test automation

<table>
<thead>
<tr>
<th>Test</th>
<th>Current Lead Time (Labor Hours)</th>
<th>Post Automation Lead Time (Labor Hours)</th>
<th>Estimated Lead Time (Labor Hours) Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual PFG calibration</td>
<td>4 hours 39 minutes</td>
<td>2 hours</td>
<td>2 hours 39 minutes</td>
</tr>
<tr>
<td>Burst tests</td>
<td>50 minutes</td>
<td>20 minutes</td>
<td>30 minutes</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5 hours 29 minutes</td>
<td>2 hours 20 minutes</td>
<td>3 hours 09 minutes</td>
</tr>
</tbody>
</table>

A sample template of what the test screen would look like for automated burst tests was developed in LabVIEW and is shown in Fig: 20, 21, 22, 23, 24, 25, 26, and 27. It can be noted in the template in Fig: 20 that there are automated interlocks and checks for parameters like pressure, end station seal etc. Once all these interlocks are satisfied, all lights turn green and now the user can select the test to be carried out from the drop down menu.

Fig: 21 shows the next stage when a specific burst test i.e. the left elevator burst test has been selected. The user is only required to click on the start button and the rest of the procedure is fully automated. A green light comes on when the procedure is successfully completed and a test report is generated and saved on to the system.
Figure 20: Sample LabVIEW test template for automated Burst tests

Figure 21: LabVIEW sample template for left elevator burst test
Figure 22: LabVIEW sample template for air bearing burst test

Figure 23: LabVIEW sample template for orienter lift burst test
Figure 24: LabVIEW sample template for orienter rotate burst test

Figure 25: LabVIEW sample template for profiler burst test
Figure 26: LabVIEW sample template for right elevator burst test

Figure 27: LabVIEW sample template for XP-VPS burst test
4.1.3. Advantages and Disadvantages/Roadblocks

The implementation of automated testing saves the labor hours as well as reduces the lead time. Minimal human interference reduces “touch time” and leaves the technician free for parallel testing either on the same or a different machine tool. Also, the automated conditional interlocks make the procedure safer.

A major disadvantage is that automation of certain tests which involve high voltage may increase the risk involved as even the smallest software glitches can cause accidents. Also, it may not be beneficial enough to justify implementation cost in older models which have a lower demand. Another roadblock is that some tests may vary slightly from model to model and thus may need additional work by the automation team before they can be implemented to all machine tools.

4.2. Parallel testing

As observed in Fig: 15, testing of UES is a very serial process. So, one way that the lead time could be reduced would be by doing multiple test procedures simultaneously in parallel. The test technician has access to two computers; the test PC and the service PC. The test PC is set up specially for testing and is detached after the final tests are completed, while the service PC is shipped with the machine and is used for running the machine tool by the customers. Under the current setup they are not set up for independent controls. To facilitate parallel testing, the two computers must have independent controls and suitable interlocks.

4.2.1. Methodology

To select candidates suitable for parallel testing, dependencies between tests were established. The dependencies were divided into following sub heads:

a) Hard dependency: These are the test steps which should be completed before a particular test can be carried out. There is no possibility of starting the given tests without fulfilling all hard dependencies.

b) Soft dependency: these are the test steps which are preferably carried out before moving on to the test under consideration. Fulfilling the soft dependencies ensures a
smoother flow, although it is not absolutely necessary to finish these before moving on to the given test.

c) Conditional dependency: this represents certain conditions like high vacuum etc. which need to be fulfilled before the test can be performed.

d) Subsystem involved: This shows the subsystems involved in the test being considered. It is clear that two tests that involve the same subsystems cannot be done in parallel.

A sample sheet of data collection is shown in Table:6.

<table>
<thead>
<tr>
<th>Test Type</th>
<th>S.No.</th>
<th>Test</th>
<th>Hard dep.</th>
<th>Soft dep.</th>
<th>Conditional dep.</th>
<th>Subsystems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wafer Handler</td>
<td>32</td>
<td>Gain margin tests</td>
<td>1,2,3,6,11,23</td>
<td>NA</td>
<td>High vacuum</td>
<td>Scan</td>
</tr>
<tr>
<td>Function Tests</td>
<td>33</td>
<td>Platen lift home offset check</td>
<td>1,2,3,6,11,23,26</td>
<td>NA</td>
<td>High vacuum</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>Scan shaft corkscrew check</td>
<td>1,2,3,6,11,23</td>
<td>NA</td>
<td>High vacuum</td>
<td>Scan</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>Y tilt cycle test</td>
<td>1,2,3,6,1,23</td>
<td>NA</td>
<td>High vacuum</td>
<td>Roplat + Scan</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>E-clamp current check</td>
<td>1,2,3,6,9,11,</td>
<td>NA</td>
<td>High vacuum</td>
<td>Roplat + Scan</td>
</tr>
<tr>
<td>Vacuum And</td>
<td>37</td>
<td>Differential seal pressure check</td>
<td>1,2,3,6,11</td>
<td>NA</td>
<td>High vacuum</td>
<td>Differential pump</td>
</tr>
<tr>
<td>Bursts Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Based on the data collected during time study, through observation of the testing process and through interviews with test technicians, a test dependency network diagram was developed which is shown in Fig: 29. The first step involved establishing precedencies between the steps by referring to the hard dependencies column. After this, the tests were divided into phases based on their hard dependencies as well as conditional dependencies. This gives us a clear idea of what tests can be considered to be candidates for parallel testing.
In Figure: 29 all tests in the same color are in the same phase, and are candidates for tests in parallel. A deeper scrutiny based on subsystems involved during the tests and other factors like safety is required. The tests listed in orange are the ones that do not require vacuum and the ones listed in blue boxes are the ones that are dependent on vacuum. The tests in square boxes in either color are the ones that need to be completed before wafer cycling can be commenced and are thus high on the priority list for timely completion.

4.2.2. Result

Based on the conditional dependencies, precedence and subsystems involved; certain test candidates have been found suitable for parallel testing. This would result in lead time reduction as multiple tests will be done in parallel. It will also save labor hours in certain cases
when a single test technician would be able to run two tests simultaneously when they do not require continuous monitoring, for example: wafer cycling and EPM calibration. Table 7 shows the lead time reduction and labor hours saved by parallel testing.

Table 7: Lead time reduction and labor hours saved by parallel testing

<table>
<thead>
<tr>
<th>Couplings for Parallel Testing</th>
<th>Estimated Lead Time Reduction</th>
<th>Estimated Labor Hours Saved</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPM calibration + Wafer Cycling</td>
<td>5 hours</td>
<td>5 hours</td>
</tr>
<tr>
<td>Cryo pump start up + XP-VPS verification test or Cryo pump start up + Angle cup verification or Cryo pump start up + Robot home offset or Cryo pump start up + Wafer walkout checks</td>
<td>30 minutes</td>
<td>None</td>
</tr>
<tr>
<td>Service PC setup + Any Other Test</td>
<td>10 minutes</td>
<td>None</td>
</tr>
<tr>
<td>Software and license verification + Any Other Test</td>
<td>2 minutes</td>
<td>None</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5 hours 42 minutes</td>
<td>5 hours</td>
</tr>
</tbody>
</table>

4.2.3. Advantages and Disadvantages/Roadblocks

Whereas on one hand parallel testing makes the lead time shorter, it also makes the process more complex. It requires setting up two separate computers with independent controls and interlocks which could be expensive and time consuming.

Also, there could be some safety concerns regarding potential of harness and cords entanglement with multiple operators running parallel tests.
4.3. **Historical data analysis**

Historical data was mined from the SAP and the Quality Notifications (QNs) were analyzed. The initial goal was to sort out tests which have never failed over the past 5 years and thus can be deleted from the procedures. But, the way the SAP system is designed does not allow for a particular fault to be traced back to a specific test. Therefore, instead of looking for "no failures", we looked for most frequent failures and did a root cause analysis.

4.3.1. **Methodology**

The QNs over the last year were sorted into major causes based on the cause of failure registered in SAP and an in depth analysis was conducted to identify the causes associated with them. A fish bone diagram was developed to identify the root cause factors for major failure mode of the last quarter i.e. vacuum leak.

Fishbone diagrams are causal diagrams that show the causes of a specific event [14]. It is commonly used for quality defect prevention, to identify potential factors causing an overall effect. Causes are usually grouped into the following major categories [14]:

- **People**: Anyone involved with the process
- **Methods**: How the process is performed and the specific requirements for doing it, such as policies, procedures, rules, regulations and laws
- **Machines**: Any equipment, tools, etc. required to accomplish the job
- **Materials**: Raw materials, parts etc. used to produce the final product
- **Measurements**: Faults in data generated from the process that are used to evaluate its quality
- **Environment**: The conditions, such as location, time etc.in which the process operates

4.3.2. **Results**

The major quality issues for the first quarter were identified at the UES as shown in Fig: 30.

There were four main causes for QNs which are as follows:

1. Connections
2. Harnessing
3. Parts shortage
4. Vacuum leak

Further investigation was carried out to get to the root cause of these errors and the main causes for each quality issue are shown in Figure: 31, 32, 33, and 34. On comparison with previous quarters’ QNs it was observed that a new issue of vacuum leak has emerged in the UES line. Therefore, a deeper analysis was carried out for the problem of vacuum leak and a fishbone diagram was developed shown in Fig: 35.

Figure 29: Broad division of causes for QNs for UES [15]
Figure 30: Root causes for connection breakdown [15]

Figure 31: Root causes for harness breakdown [15]
The fish-bone diagram based on the quality data was developed as shown in Figure: 34.
Further investigations were carried out into each root cause and it was found that incorrect lay lines and wrong size of O-ring were the two major root causes of the vacuum leak. It was recommended that bottom of process chamber be reworked to remove lay lines and converted to 32 Jitterbug finish. It was also recommended that custom made O-rings of bigger diameter be used for better fit to avoid stretching.

4.4. Push back to supermarket

Some of the tests need not be done at the module level. Individual components may be tested in the supermarket beforehand to save time during the module tests.

4.4.1. Methodology

All components being tested at UES mod level that were sourced through supermarket were identified. Interviews and discussions were held with test team and supermarket personnel and in depth analysis of the test procedures was done to identify the tests which did not necessarily need the component to be assembled and powered up before testing.
4.4.2. Results

The Scan Motor Alignment test was found to be the only test which qualifies the above criteria and has a procedure that can be done at the supermarket. This will reduce the lead time of the UES testing but would still require the same amount of labor hours.

Table 8: Estimated lead time reduction by shifting a test to supermarket

<table>
<thead>
<tr>
<th>Test</th>
<th>Estimated Lead Time Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scan Motor Alignment</td>
<td>1.25 hours</td>
</tr>
</tbody>
</table>

4.4.3. Advantages and Disadvantages/Roadblocks

To perform the scan motor alignment in the supermarket a high pressure air supply system of up to 85psi needs to be set up for proper alignment of the air pads to be mounted in vertical position.

4.5. Redundant Test Analysis

If tests being repeated at the supermarket and at the module level could be eliminated, it could reduce the lead time for the UES.

4.5.1. Methodology

UES component list was obtained and the ones coming through supermarket were marked out. The supermarket test procedures on AGILE software were compared to the module testing to see if there was any redundant testing.

4.5.2. Results

XP-VPS leak check is done at the supermarket level before being assembled and then again at the module level post assembly. Although the test is redundant, yet recommending it to be removed from the module tests could cause quality issues as the final leak test after installation is of extreme importance.
4.6. Simultaneous test and build

The idea to begin testing while the UES was still being assembled was also explored. But, due to certain roadblocks this does not seem feasible. One major issue is that almost all tests need power supply, but powering up the machine in assembly bay is not only cumbersome but also a huge safety hazard for the assemblers who will need to work around the power cables. Therefore, this path for test lead time reduction was not pursued further.

4.7. Summary

It can be observed from the Table: 9 that a total lead time reduction of approximately 10 hours and a labor time saving of about 8 hours can be achieved by applying the changes mentioned in the preceding sections. This amounts to around 8.4% reduction in lead time and 16% in labor hours.

Other than this, regular historical analysis and root cause analysis can save significant amounts of rework and reduce failures in testing. This can have a significant impact on the overall first pass yield improvement.
Table 9: Total Lead time reduction achieved through various processes and the tests selected for each process

<table>
<thead>
<tr>
<th>Path</th>
<th>Tests Identified</th>
<th>Estimated Lead Time Reduction</th>
<th>Estimated Labor Hours Saved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automated Testing</td>
<td>Dual PFG calibration</td>
<td>2 hours 39 minutes</td>
<td>2 hours 39 minutes</td>
</tr>
<tr>
<td></td>
<td>Burst tests</td>
<td>30 minutes</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Parallel Testing</td>
<td>EPM calibration + Wafer Cycling</td>
<td>5 hours</td>
<td>5 hours</td>
</tr>
<tr>
<td></td>
<td>Cryo pump start up + 12/13/14/15</td>
<td>30 minutes</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Service PC setup + Any Other Test</td>
<td>10 minutes</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Software and license verification + Any Other Test</td>
<td>2 minutes</td>
<td>None</td>
</tr>
<tr>
<td>Push back Tests to</td>
<td>Scan Motor Alignment to</td>
<td>1 hour 15 minutes</td>
<td>None</td>
</tr>
<tr>
<td>supermarket</td>
<td>supermarket</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Lead Time Reduction</td>
<td></td>
<td>10 hours 06 minutes</td>
<td>8 hours 09 minutes</td>
</tr>
<tr>
<td>% Lead Time Reduction</td>
<td></td>
<td>8.4%</td>
<td>16.3%</td>
</tr>
</tbody>
</table>
Chapter: 5

5. Conclusions and Recommendations

5.1. Conclusion

In this chapter, we present the conclusions that we have drawn from the work presented in this thesis. We also present the conclusions and recommendations from related work done by Sedore [12] and Jain [13].

With the goal of reducing the lead time for the UES, this thesis presents six paths that were explored, namely automated testing, parallel testing, historical data analysis, push back to supermarket, redundancy testing and; simultaneous test & build.

A decision tree was developed to select suitable candidates for automation of testing. Two major candidates were identified for the first phase of implementation and their sample templates were built in LabVIEW. It was concluded that automation of the selected candidate tests will cut down the labor hours and the lead time by 3 hours and 9 minutes.

For the analysis of second path and to shortlist candidate tests for parallel testing a dependency network diagram was developed. The constraints of hard dependency, soft dependency, conditional dependency and subsystems involved were considered. The analysis of network diagram was performed to shortlist tests for parallel testing which will reduce the lead time and labor hours by approximately 5 hours 42 minutes.

Analysis of historical quality data collected from SAP was conducted to perform the root cause analysis of most frequent failure modes in the last quarter. A fish bone diagram was developed to indicate various causes for vacuum leak at UES.

All tests that could be pushed back to the supermarket were listed along with the apparatus necessary for implementation in supermarket. Attempts were also made to list out any tests that were being done at supermarket and then again at module level, to pinpoint redundancies.
The option of simultaneously building and testing machine in the assembly bay was explored initially but was found to be infeasible due to various safety concerns.

Related issues around the process were explored by Sedore [12] and Jain [13]. Sedore’s [12] thesis focused on developing a cyclical schedule for labor management; Jain [13] worked on improved kitting procedures at warehouse. It is concluded that implementation of recommendations from all three thesis will result in lead time reduction of approximately 73% in assembly and 20% in testing.

5.2. Recommendations

The primary recommendation derived from this thesis is that VSEA should make an attempt to automate the whole testing procedure. This thesis focuses on certain tests which should be the first few candidates because of the ease of automation. But the attempt should be to extend the automation to all tests which can be safely automated. Also, the automation programs developed in LabVIEW should ultimately be integrated with VCS; this will further cut down on the time taken to download the LabVIEW setup for testing on each machine. The automation of testing also makes it safer as conditional interlocks can be set up.

Secondly, VSEA should set up the service PC and the test PC as independently run systems and thus enable two tests to be done in parallel. Also, the automation of more and more tests will increase candidates suitable for parallel testing as less human intervention is required and there will be less space overlap and safety issues.

Thirdly, Varian should investigate and refine their data collection methodology. The current system does not link the faults found during the module testing to the corresponding test. If this is ensured, then the testing of components that never give errors historically may be declared redundant and phased out. Currently wafer cycling test is done up to 2500 uninterrupted cycles, this number could be reduced over a period of time based on historical data analysis of when failures happen. For this, every Quality Notification (QN) should be associated with a testing procedure in the database.
We also recommend that VSEA should further explore the possibility of pushing tests back to the supermarket or the vendor. A high pressure air system should be made available at the supermarket to facilitate the Scan Motor alignment test. Pre tested components should be made available at the module assembly to minimize the post assembly tests to be carried out.

Further, based on the related work done by Sedore[12] we recommend that Varian should develop build schedules for all UES models using the critical path method described in Sedore's[12] thesis. The related data should also be updated in Varian's Lotus Notes database for use with all future builds. Also, Varian should record the instance and duration of all material shortages that disrupt an assembly form following its build schedule. This will allow for the impact that a material shortage has on the assembly lead time to be quantified. Communicating this information to material planners and vendors would then allow for corrective actions to be taken for future orders.

Based on the related work done by Jain [13], we recommend that existing Z-pick kit codes for all the modules- Source, Analyzer, Corrector, and UES should be reviewed and evaluated. Most kit codes have parts grouped in an ad-hoc manner. These kit codes need to be replaced with new kit codes, which have parts grouped by procedure or sub-module. Also, it is strongly recommended that Logbooks should be updated with the correct sequence of sub-modules and tasks. The kit codes associated with each sub-module should be mentioned at the top of the page to make it easier for the assembler to identify the kit required for the current sub-module.
Chapter: 6

6. Future work

There are several directions in which the work presented in this thesis can be extended in the future. A major area would be to apply the automation and parallel testing algorithms to modules other than UES. The UES currently has the longest lead time, but reducing the lead time and labor hours at other lines would definitely be beneficial to VSEA.

Another major area would be the integration of SAP, AGILE and other data collection systems within the company. The resources between the various departments are shared and having a shared data-sharing platform will make the processes more efficient and data mining easier.

Further work could include lean manufacturing steps like installing dynamic display boards all over the production floor to ensure that each worker knows the current status of the build and delays in work. Sedore’s [12] thesis states that to reduce the lead time, the module on the critical path should never be abandoned and a worker should always be working on it. These boards would help arrange and schedule workers accordingly.

Varian can extend the critical path method used in Sedore’s [12] thesis to other assembly lines. Lowering lead times reduces WIP which lowers the total investment in in-process inventory, increases the visibility of part shortages, decreases shop floor congestion, etc.

The use of a build schedule enables shift schedules to be created for each person, for each shift of the build. Shift schedules allow for clear communication of End of Shift Targets for each worker. Varian could incorporate a system of incentives for individual workers or for shifts that consistently achieve their targets, or for the UES line as a whole for achieving lead times of less than 48 hours. These could be based on weekly, monthly, quarterly, or annual performance, and could range from monetary incentives such as bonuses, to gift giveaways, or additional paid time off.
Sources Cited


