

# **Lean Manufacturing in a Mass Customization Plant: Improved Efficiencies in Raw Material Presentation**

by

Moojan Daneshmand  
B.S. in Mechanical Engineering,  
University of Florida, 2009

Submitted to the Department of Mechanical Engineering  
in partial fulfillment of the requirements for the degree of

Master of Engineering in Manufacturing

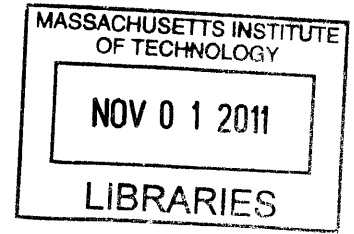
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## **Abstract**

This thesis focuses on the application of the principles of lean manufacturing at Varian Semiconductor Equipment Associates (VSEA). The company faces the challenges of highly customized assembly as well as fluctuating demand, both of which cause lead times that are longer than expected.

Value Stream Mapping was used to identify the main sources of waste in the VSEA manufacturing plant. After evaluating all factors contributing to longer cycle times, it was found that one of the main problems encountered by VSEA was unorganized presentation of raw material to the shop floor.

Using the 5S methodology, a framework was created to appropriately categorize the raw material into smaller groups, and deliver them to the flow line according to Just-in-Time (JIT) principles. After the new presentation method for raw material is implemented, the cycle time will be reduced by 6% due to the elimination of the non value added activity from the process. In addition, the first steps toward kaizen process improvement will be in place.

Thesis Supervisor: Stephen C. Graves

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# Table of Contents

<b>1. Introduction .....</b>	<b>9</b>
1.1 The Semiconductor Equipment Industry.....	9
1.2 Company background .....	10
1.3 Company Need .....	13
<b>2. Description of Operations at VSEA .....</b>	<b>15</b>
2.1 Company-Specific Language .....	15
2.2 Manufacturing Operations.....	18
<b>3. Problem Statement.....</b>	<b>23</b>
3.1 Unnecessary Non-Value-Added operations .....	23
3.2 Inefficient Information and Material Flow .....	28
3.3 Testing Processes .....	32
3.4 Materials Management.....	35
3.5 Summary .....	41
<b>4. Review of theoretical background .....</b>	<b>42</b>
<b>5. Methodology .....</b>	<b>46</b>
5.1 Preliminary analysis.....	46
5.2 Improved Efficiencies in Raw Material Presentation Methodology .....	51
<b>6. Raw Material Presentation Analysis .....</b>	<b>56</b>
6.1 Problem overview .....	56
6.2 Proposed Logic for Kitting of Parts .....	56
6.3 Cost and Benefit Analysis .....	65
<b>7. Conclusion and Future work .....</b>	<b>67</b>
7.1 Conclusion.....	67
7.2 Future work .....	67
7.3 Summary of Ideal and Future State Value Stream Maps .....	68
<b>8. References .....</b>	<b>70</b>

## List of Figures

Figure 1: A few modules of a Varian ion implanter machine.....	13
Figure 2: Semiconductor Equipment revenues in billions of dollars, 2007–2012(forecast).....	14
Figure 3: Varian’s Gloucester facilities illustration (not to scale).....	19
Figure 4: Parts arrive in kits from different warehouses.....	25
Figure 5: Current kits presentation on the flow line.....	26
Figure 6: Parts sourcing for Module assembly line from internal suppliers.....	28
Figure 7: Material and information flow between Building 80 and the Flow Line .....	30
Figure 8: Shortages on High and Medium Current tools affected by demand Q3’07 to Q3’11 ...	37
Figure 9: Snapshots of WIP inventory for the 90° Module.....	39
Figure 10: Current kit code system.....	52
Figure 11: 5S methodology.....	54
Figure 12: 5S methodology consideration.....	55
Figure 13: Color coding .....	58
Figure 14: Localized kitting at a single warehouse.....	59
Figure 15: Material pick list sample .....	62
Figure 16: Sealed completed kit .....	64

## List of Tables

Table 1: Varian’s product offerings .....	11
Table 2: Production areas and their tasks .....	19
Table 3: Top contributors to QNs filed for 90° and Terminal Modules .....	34
Table 4: Top shortage instances observed on the 90° module and their duration .....	36
Table 5: Most frequently failed parts .....	60
Table 6: Estimated production lead times .....	68

# 1. Introduction

This section serves to deliver an overview of the semiconductor equipment industry, background information about Varian Semiconductor Equipment Associates and the needs of the company at the point at which the project was conceived. Thereafter, Varian's operations are described. The product offerings are listed, and the product architecture and functioning of the modules of the tool are described in short. Finally, the section on the company's needs introduces the problem posed by the company managers.

## 1.1 The Semiconductor Equipment Industry

Semiconductor wafer manufacture, depending on the manufacturer, requires about 18 different types of primary equipment for processes of etching, ion implantation, sputtering, chemical vapor deposition, testing and assembly and packaging. The price of each piece of equipment runs in the millions of dollars mainly because of complexity of design and manufacture, and the use of expensive materials. Thus, the cost of building a semiconductor fabricating facility, also called a 'fab', can be up to \$5 billion.

Fabs purchase new equipment either to increase capacity, to change to different wafer sizes or when starting a new technology line [1]. Each chipmaker has unique 'recipes' or treatments that it performs on the wafer to get the desired composition of the silicon wafer. Thus, each chipmaker requires unique pieces of equipment customized to suit specific requirements. Moreover, the size of the equipment complicates the logistics of installation for the chipmaker

and thus requires the equipment maker to be flexible in terms of shipping dates. Sun [2], Jia [3] and Konisky [4] cite the high barrier of entry created by the capital intensive nature of the business as a reason why chipmakers exert so much buyer influence on equipment makers and why the latter comply with any customer request, at any stage of production. The high level of customization demanded by customers and the complicated design and size of the equipment make manual assembly of the final product the only feasible process.

## **1.2 Company background**

### **1.2.1 Overview**

Varian Semiconductor Equipment Associates, Inc. (VSEA) is a designer and producer of ion implantation machines. Ion implantation constitutes a critical step in the manufacture of integrated circuits. VSEA was founded in 1975 in Gloucester, Massachusetts by Varian Associates' acquisition of Extrion Corporation. Today Varian is the world's leading ion implantation equipment company with a dominant market share in the high current, medium current, high energy and plasma doping equipment categories. Their customers include the world's biggest chipmakers including amongst others Intel, Samsung, IBM, Sony, Texas Instruments and Global Foundries. VSEA has its own research and development function and manufacturing facilities, and it markets and services its equipment worldwide [5].

### 1.2.2 Product offerings

Ion implantation or doping is employed in semiconductor fabrication to introduce charge carriers in the crystal lattice of the semiconductor [6]. Varian's products are categorized based on the energy intensity and level of doping the product delivers. The product families are namely High Current (HC), Medium Current (MC), High Energy and Ultra High Dose or VIISTA PLAD. The '200 mm' or '300 mm' identifier refers to the size of the wafer which will be processed by the equipment. The products are referred to as 'machines' or 'tools'. The basic product variants are grouped in table 1.

**Table 1: Varian's product offerings**

<b>High Current (HC)</b>	<b>Medium Current (MC)</b>	<b>High Energy</b>	<b>Ultra High Dose (PLAD)</b>
VIISTA HCP 200 mm	VIISTA 810XP 200 mm	VIISTA 3000 XP 200 mm	VIISTA PLAD 200 mm
VIISTA HCP 300 mm	VIISTA 810XP 300 mm	VIISTA 3000 XP 300 mm	VIISTA PLAD 300 mm
VIISTA HCPv2.0	VIISTA 900XP 200 mm		
VIISTA HCS 300 mm	VIISTA 900XP 300 mm		

### **1.2.3 Product architecture and functioning**

The product architecture is modular. The modules which constitute an ion implanter are the beam line module, the end station and the control station. The modules contain mechanical as well as electronic sub-assemblies. These modules are customizable to certain extent based on customer specifications.

The beam line module contains foremost an indirectly heated cathode source which ionizes the dopant gases like Boron or Arsenic. The ions are generated in the form of a beam, and this beam is modulated by means of powerful magnets and electrostatic lenses. A dose system controls the exposure time of the beam upon the semiconductor wafer which ultimately determines the ion concentration of the doped wafer [7].

The end station module contains chambers where a fab engineer can load wafers to be doped. It also contains mechanisms to take one wafer at a time, expose it at the right position and orientation to the beam arriving from the preceding beam line module, and to withdraw an implanted wafer that is to be moved to the next stage of fabrication [7].

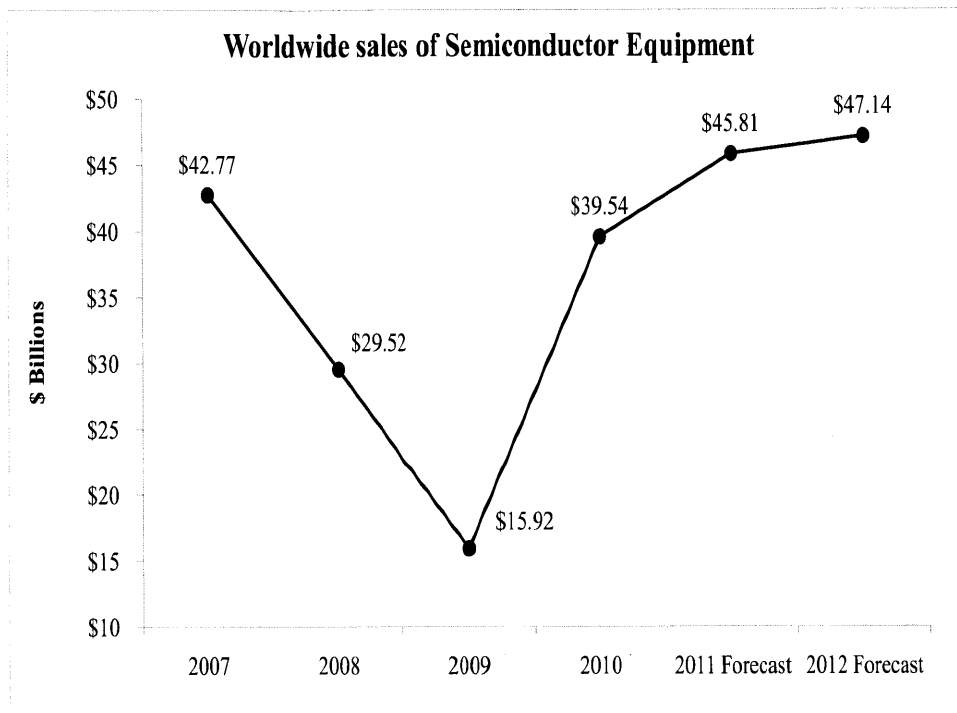
The critical parameters which determine the implantation quality are namely wafer orientation, wafer charge level, vacuum level within the tool, doping energy, wafer temperature and the number of scans the beam performs upon the wafer. Automated control over these parameters is achieved by means of the control system, which consists of computer hardware and software. The control system also provides real time information useful in production, as well as in diagnostic and maintenance tasks [7]. Figure 1 shows the modules of a typical Varian machine.



**Fig.1. A few modules of a Varian ion implanter machine**

### **1.3 Company Need**

The company executives presented the company situation and a brief statement on what they expected the project should address at that point [8]. The semiconductor industry was witnessing growth in revenues after a collapse in sales in the years 2008 and 2009. The industry witnesses cyclic periods of growth and slump. The data from 2010 revealed that the industry was renewing itself, and the forecast for 2011 and 2012 was expected to exceed pre-2008 levels. Figure 2 shows the trend from 2007 and forecast till 2012 [1].



**Fig.2. Semiconductor Equipment revenues in billions of dollars, 2007 – 2012 (forecast)**

At this juncture, the company wanted to meet the growing demand not by making a capital investment to expand their facilities, but by weeding out the inefficiencies in their operations. Specifically, the company wanted the team to help identify methods of reducing the labor hours and cycle time required to build a tool. The company had some prior experience in applying techniques of lean manufacturing to remove wasteful processes from their operations. The manufacturing engineering team now wanted to do a more detailed analysis of the operations, and implement improved systems and processes with the objective of reducing the costs, resources and time required in manufacturing.

## 2. Description of Operations at VSEA

### 2.1 Company-Specific Language

Company and industry terminology make up a large part of daily dialogue at Varian. It is essential to introduce some terms which may occur often in this thesis.

#### 2.1.1 Types of orders

A *Machine Order*(or *Tool Order*) is an order placed by a customer. These orders are received by sales representatives. The machine order will contain information about the shipping date, terms and conditions, and price. Each machine order may include specific requirements and different options specified by a customer.

A *Sales Order* is the order placed by a customer for spare parts. Some sales orders may be assigned higher priority than others. An *Emergency Order* or EMO is the highest priority item.

A *Production Build Order* (PBO) is a very detailed machine order. It is used by the operators to know which configuration options are requested by the customer. A PBO can change upon customer request at any time 10 days prior to the shipping ‘freeze period’, during which changes can no longer be made to the PBO.

A *Shop Order* is issued to an operator to build a single assembly or to perform machine testing. Shop orders have different levels. For example, at the higher level, a single shop order can be

issued for the assembly of an entire module. At the lower levels, shop orders will be issued to different sub-assemblers for each subassembly in the tool.

An *Engineering Change Order* (ECO) is issued when a design change is to be implemented. The design change occurs for various reasons such as machine upgrade, part quality issue especially at customer site or supplier design change. Once an ECO is approved, the change is applied to the machine and it will be a part of the procedure thereafter.

### **2.1.2 Bill of Materials**

A *Bill of Materials* (BOM) is the list of all the parts required for the assembly of a tool. It specifies the quantity of each part, its storage location and the kit code under which the part is grouped. The BOM of a typical tool contains around 1200 parts depending on its configuration and options requested by a customer.

### **2.1.3 Kit codes**

Since the BOM of a tool may contain over 6000 parts, it is impossible to keep these parts on the shop floor. Most of the parts needed are housed in company or supplier warehouses. These parts can be ordered or ‘pulled’ from the warehouses by the shift supervisor when they are needed, ordering in advance to account for the lead time of delivery of the parts. To simplify the pulling of parts from warehouses, parts have been grouped in kit codes which roughly correspond to the build procedure. A kit for a module can contain anywhere from 1 to 300 parts. The parts have been grouped roughly in such a manner that parts in one kit have to be assembled closer in time

to each other than parts in other kits. There are two types of kit codes – Z-pick kit codes, and Z-pick lists. Z-pick codes are used for parts stored in an external storage location, called Building 80 and the kits are usually pulled 24 hours before module assembly is begun. The Z-pick lists are kits of parts stored in an indoor location. These are the parts needed for the base configuration of the machine. The modules each require about 15 kits. The large size of kits reduces visibility about shortages in a kit, and also causes operators to search for a particular part for a long time.

#### **2.1.4 Other terms**

A *Laydown Date* is the date on which a module assembly is set to begin. The first step in the assembly of any module consists of laying down a Higher-Level Assembly (HLA) frame in the assembly bay. The production schedule is driven by MRP logic, and back-calculates a scheduled laydown date based on a shipping date, and planned lead times. However, the production supervisor makes the day-to-day decision on which tool is to be laid down, and on which date, subject to last minute scheduling changes and parts availability.

*Varian's fiscal calendar* for a year begins on October 1 of the previous calendar year, and ends on September 30 of that year. The production planning and control as well as financial reporting are done on a quarterly basis, starting on October 1 of the fiscal year.

A *Purchase Order* is an order for raw material released to a supplier. A purchase order contains an itemized list of parts needed, their quantity and the agreed price of a part. When a part is delivered by a supplier, the receipt is checked against the purchase order to see if the delivery is complete or not. It is common for items on the purchase order to be delivered at

different times by the supplier. The status of purchase orders can be checked in the company's enterprise resource planning system, SAP.

## **2.2 Manufacturing Operations**

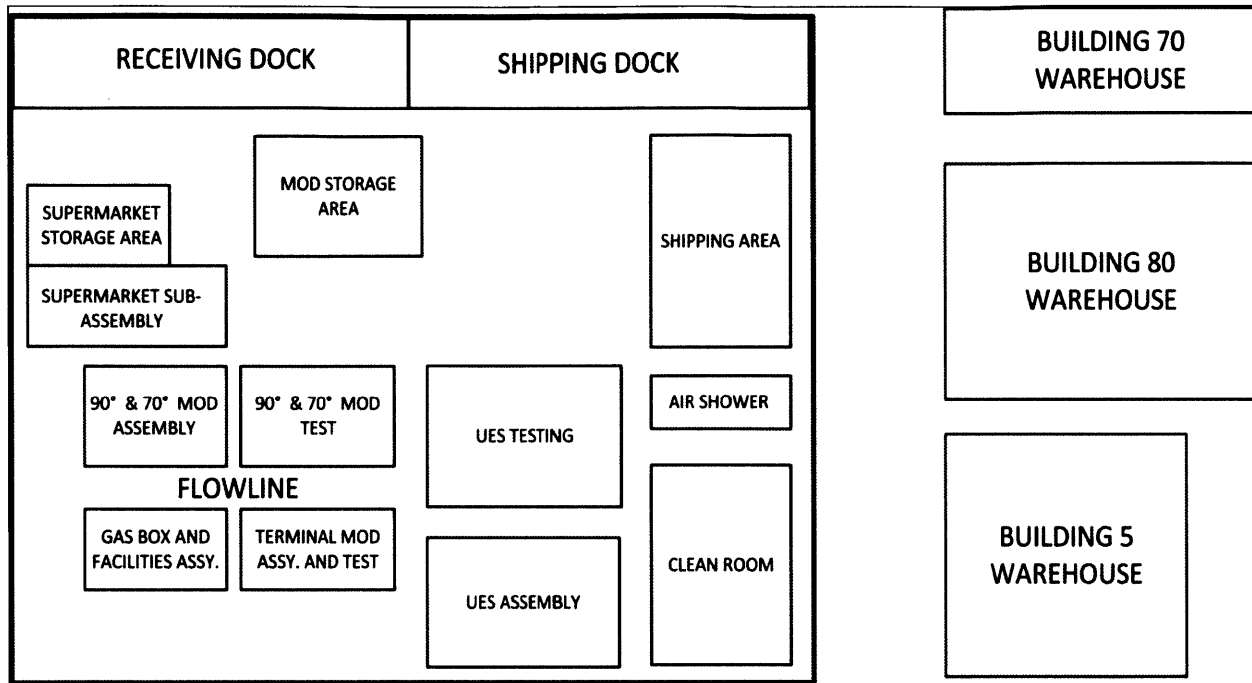
### **2.2.1 Overall operations**

Varian manufactures a number of different products from its single manufacturing facility in Gloucester. The company receives either pre-fabricated parts or sub-assemblies from its global supplier base. The facility first assembles different sub-assemblies and the different modules which constitute the machine. Thereafter, the testing of the tool can be done in two ways. If the customer orders a 'Full Build' machine, the different modules of the machine are assembled in a clean room, and the machine as a whole is tested. After testing, the machine is disassembled into the modules, which are then shipped separately in different crates. The machine must then be assembled on site. To reduce the time which went into assembling and then disassembling the machine, Varian began a new system called Smart Ship. Under this system, the individual modules are tested separately and then shipped in different crates. This method saves about 400 man-hours in assembly time. Presently, about 75% of the customer orders adopt the Smart Ship process, and the remaining 25% are built as per Full Build procedures, because of customer mandate.

### **2.2.2 Production areas**

The production floor is divided into different zones that manufacture and test different sub-assemblies and modules. The division of work content is summarized in table 2. In the next

section, the Flow Line zone is explained in greater detail. Figure 3 depicts the production areas and the warehouses at Varian's Gloucester facilities.



**Fig.3. Varian's Gloucester facilities illustration (not to scale)**

**Table 2: Production areas and their tasks**

Zone name	Work done
Supermarket (SMKT)	Building and testing different sub-assemblies which are installed in the module assembly downstream
Flow Line	Building and testing of the 90° and 70° modules for the High Current machines
	Building and testing of the Beamline and Terminal modules for the Medium Current machines

	Building and testing of the Gas Box and Facilities modules for High and Medium Current machines
Universal End Station (UES)	Building and testing of the Universal End Station module for both High and Medium Current Machines
Clean Room	Assembles tools for Full Build machine orders
Air Shower	Modules are disassembled, cleaned and wrapped
Shipping Area	Final inspection, packaging and crating
Receiving and shipping docks	Receiving of parts from warehouse, suppliers, and dispatching machines to customers

#### **2.2.1.1 Flow line**

The Flow Line zone is the area where the Beamline modules of both the High Current and Medium Current machines are assembled and tested. This line is also commonly called the ‘Mixed Module Line’ attributable to the number of different types of modules being worked on. The Flow Line name is a misnomer in that the modules do not flow from one build station to the next. Once the module frame or the Higher Level Assembly (HLA) is laid down in an assembly bay, it stays there until assembly is complete or until it is almost completely assembled to be moved to an open test station. For the High Current machine, this involves the assembly of the 90° and 70° modules. For a Medium Current machine, the assembly of the Beamline and Terminal Modules is done here. The testing of these modules depends on whether or not the build is a Smart Ship or a Full Build. A small section of this zone is also devoted to the assembly and optional testing of the Gas box and Facilities module.

The production is done in three shifts: first shift and second shift which work regular hours on weekdays, and a 'fourth' shift which works longer hours on the two days of the weekend and one day of the week. Note that the Flow Line does not operate daily during the third shift of production. The High Current machine's 90° module and the Medium Current machine's Terminal module involve the most work content, and thus take longer to assemble and test. The assembly and testing of these modules were focused on to identify manufacturing bottlenecks.

The build and test for a 90° module requires on average about 5 and 4 days respectively, depending on the configuration. The corresponding times for a Terminal module are 4 and 3 days respectively. However, high level of product customization, last minute customer requests, material shortages, and testing failure and rework cause the production cycle time to be highly variable, and nearly impossible to predict.

The mixed module line is not the bottleneck of the entire process. The bottleneck is actually the testing and assembly of the Universal End Station module. However, the mixed module production line is the focus of our project. This is because improvements in the mixed module area can potentially free up space and labor which can be devoted to the Universal End Station which has significantly more work content and requires greater resources. Freeing up the resources for the End Station can then bring down the cycle time of this bottleneck process, thereby increasing throughput. Thus, the capacity can be increased without expanding the facility.

### **2.2.3 Part storage locations**

Varian houses its parts inventory at different locations within its premises. These locations are **Building 80 or Warehouse, Building 70, Building 5 and MOD** storage area. Building 80

carries inventory of relatively small parts required on a daily basis at the Supermarket or the module assembly lines. Building 5 and Building 70 stock large sized parts like machine enclosures. The MOD storage area carries parts needed on the Flow Line and is located close to the Flow Line in the same building. The inventory in these storage locations is driven by a Materials Requirement Planning (MRP) system. Knowing the shop order, the machine delivery date, and the production lead time, the MRP system calculates when a particular part is needed to be delivered to the production floor from the storage location. It takes into account the lead time of the suppliers and provides an estimate of how much inventory is needed on hand to fulfill the expected demand.

The inventory in these storage locations is pulled by means of the kit codes. Varian's suppliers also carry some inventory on their end. Presently, about 55% by value of the total Cost of Goods Sold (COGS) is controlled by a Kanban system. Under the Kanban system, the supplier gets a signal to deliver a specific part only when it is used up during the production process.

### **3. Problem Statement**

In this section, the operational problems discovered by first-person observations and by preparing value stream maps are described. The focus of the observations was on the assembly and testing for the High Current (HC)90° module and the Medium Current (MC) Terminal module. The intent in the observations was to identify non-value added activities and inefficient work practices which caused more time to be spent in the production of the tool than warranted by the work instructions.

After brief descriptions of some of the major problems, the focus will be directed on the issue of raw material presentation to the shop floor which was found to be one of the main problems in their production. The rest of the thesis will be devoted to documenting this problem and testing the proposed solution. Some of the other problems are addressed in Chen's thesis [11] and Raykar's thesis [9].

The problems observed in Varian's operations can be grouped into the following categories:

1. Unnecessary Non-Value-Added operations
2. Inefficient information and material flow
3. Testing Procedure
4. Materials Management

#### **3.1 Unnecessary Non-Value-Added operations**

Non-value added (NVA) operations are those which do not add any value to the product. These can be of two types – necessary and unnecessary. Necessary NVA operations are those which for

various reasons cannot be entirely eliminated (e.g.: inspection, transporting parts). Unnecessary NVA tasks are those that can be eliminated without affecting the process or diminishing the value of the product. Identifying and eliminating these operations is valuable in terms of increased efficiency of production. The main contributors to unnecessary NVA were found to be: Work Procedures in Flow line; Parts Searching Process; Supplier Quality Issue; and Repetitive kitting and auditing.

### **3.1.1 Work procedures in flow line**

As described in section 2.2.1, the operations in the flow line can be mainly divided into two sections - assembly and testing. The assembly of both the High Current 90° module as well as that of the Medium Current Terminal module contains 10 steps, each of which contains many sub-steps. In total, both assembly procedures contain hundreds of sub-steps. The work instructions for these procedures are documented in the company's log book system.

Although the instructions of each sub-step are all understandable, they are not standardized enough for an operator to know the exact sequence of operations inside each sub-step. In other words, with the current procedure, operators can still carry out each sub-step in various ways. Some operators can do some of the same operations in a more efficient manner taking far less than stipulated labor hours. Also, if done in a wrong way, some sub-steps would require several hours of rework.

### 3.1.2 Parts searching process

As mentioned in section 2.1.3 parts are grouped by kit codes and pulled from the warehouses by the shift supervisor. Currently the kits are not organized, and each kit may contain up to 300 parts. There can be parts from different warehouses in the same kit as shown in Fig.4.

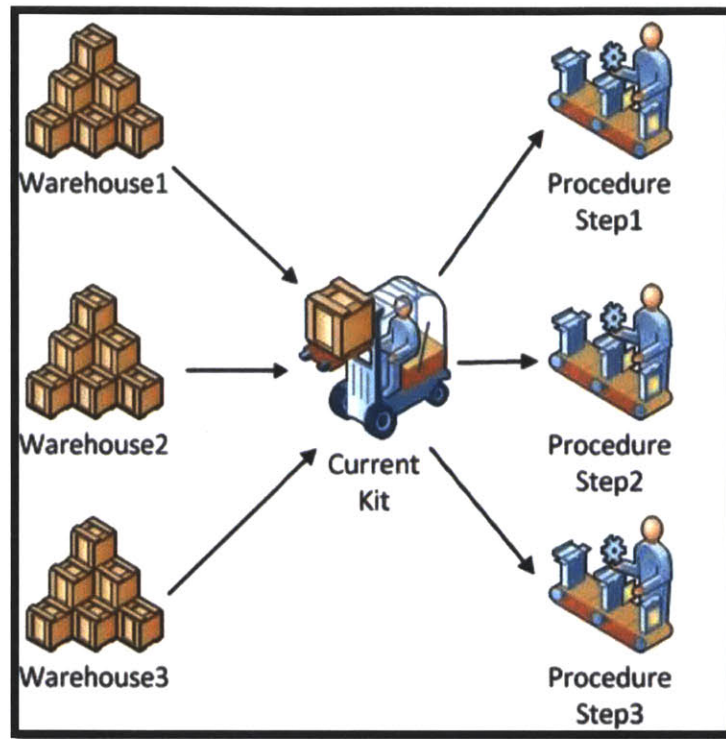


Fig.4. Parts arrive in kits from different warehouses

The kits which are pulled arrive on the Flow Line in bins and boxes without any specific label. They are all placed on racks next to the tool as shown in Fig.5, and an operator collects parts from there as needed. The large size of kits reduces visibility about shortages in a kit, and also causes operators to look for a particular part for a long time.



**Fig.5. Current kit presentation on the flow line**

Thus in the current situation, the operators need to look through all the bins and boxes in order to find a part among all the kits which got delivered on the line. Additionally, since there is no shortage notification system along with the kits delivered, the operators need to look in all the bins before detecting that the kit is incomplete. No value is added during the searching process, and it can be eliminated if there is a proper organizing system for the parts and improved communication of material flow.

During first person observations, there were instances where operators spent up to 30 minutes looking for a part for a task that may take an hour to perform. This means that 50% of the total working time was NVA. According to the VSM, the NVA time ranged from 20%-50% of the total working time at different steps. The proposed solution to this problem will help the company to reduce the cycle time by reducing the NVA. Moreover, it is the first step towards a system of Kaizen process improvement.

### **3.1.3 Supplier quality issue**

Except for the sub-assemblies that come from Supermarket area, all parts needed on the assembly line are from third party manufacturers. The materials and parts that come from the suppliers are often not in a ready-to-assemble state. Most of the time, the unclean parts need to be taken apart and cleaned in order to avoid potential rework. Also, parts coming from suppliers still carry their packaging material on them. Line operators spend a lot of time removing the packaging boxes, wrappings and shipping attachments.

In addition, some materials have quality issues. Thus, extra non-assembly work like tapping, filing and sanding is necessary before an assembly can be done correctly. These cleaning and reworking operations can be eliminated if all the suppliers can offer clean parts that meet the design. Hence they are also deemed as unnecessary non-value-added operations.

### **3.1.4 Repetitive kitting and auditing**

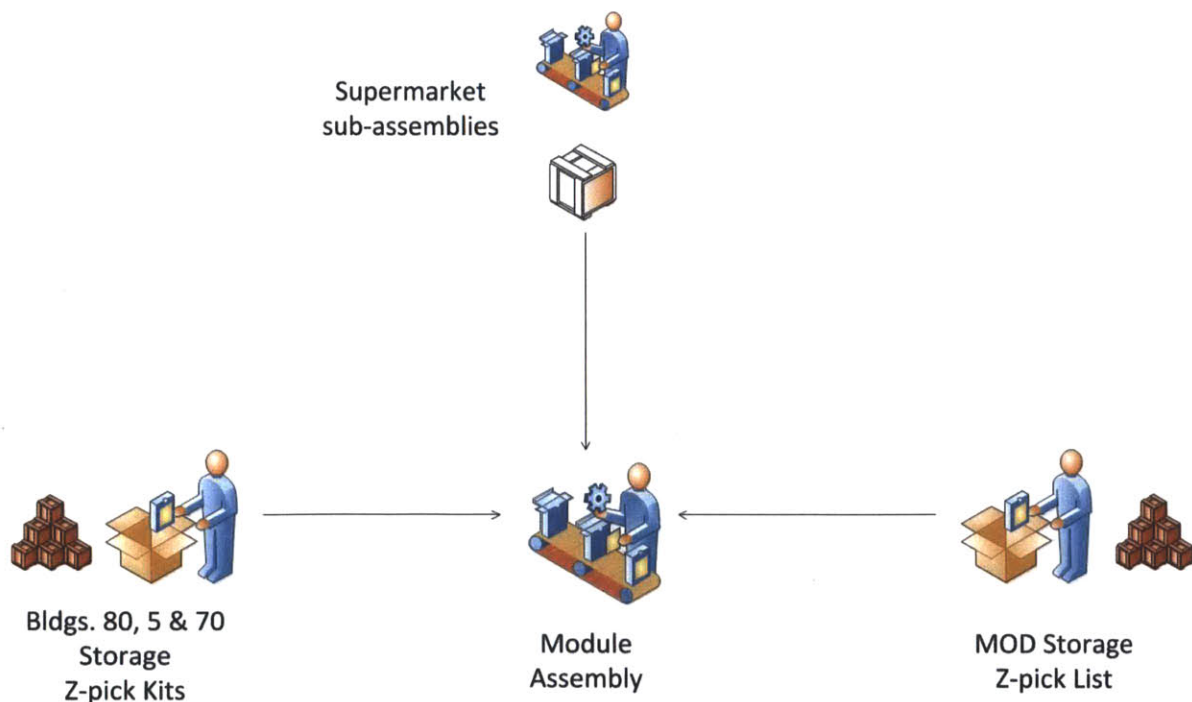
Some kits go to the flow line after being pulled from the warehouse, and do not get assembled on the modules. These kits are shipped with either the 90° module or the Terminal module directly to the customer after the module is fully assembled. Assembly operators audit the kits to ensure their completeness. Since the parts are already counted and checked at the warehouse when the material handler picks those kits, this auditing work on the flow line is considered as repetitive work.

In addition, at times the operators need to add parts and hardware to some of the kits. The operator opens the kit, audits them and adds the hardware. Since this hardware is stored at both the flow line area and the warehouse areas, it can be added to the kits when the kits get picked at

the warehouse. Since the kits will be counted twice at two different locations, the double counting is deemed as an unnecessary NVA task. There is no specific reason why operators on the line need to do this auditing/kitting process. This auditing/kitting process takes about 90 minutes of an assembler's time, which could be performed more efficiently by a picker in the warehouse.

### 3.2 Inefficient Information and Material Flow

The material needed for assembly on the mixed module line comes from three sources namely. The Supermarket area, external storage locations Buildings 80, 5 and 70, and the MOD storage area on the shop floor. As Fig.6 shows, the Flow Line uses three different communication systems – MRP, Z-pick and Z-pick List – to pull material from the three different sources.



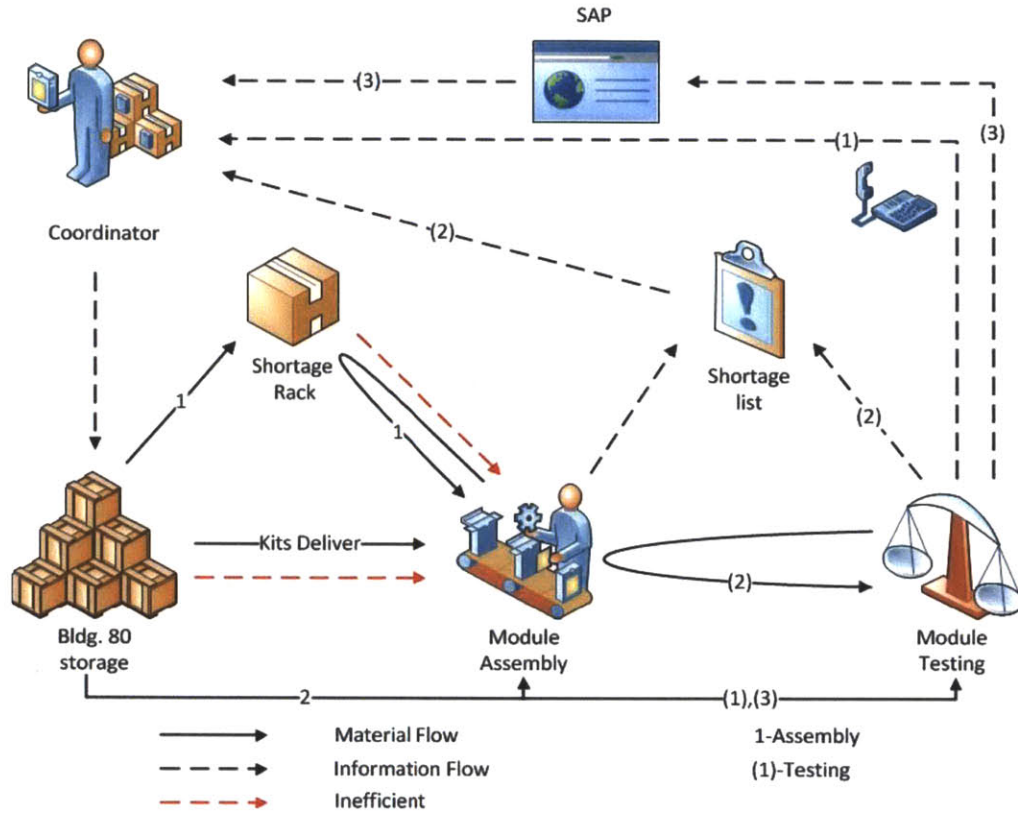
**Fig.6. Parts sourcing for Module Assembly line from internal suppliers**

The parts from the supermarket area are pulled using the MRP system based on the modules' scheduled shipping date. The parts from warehouse are pulled by the production manager 24 hours ahead of the actual needed time using Z-pick kit codes, which were discussed in section 2.1.3. Parts stored in the MOD inventory area are grouped and pulled 24 hours ahead of need as per a Z-Pick List, as discussed in section 2.1.3.

The material flow and its communication between the MOD and Supermarket areas, and mixed module line are simple and clear because these areas are close to the mixed module line. However, the material flow from the other warehouses, especially Building 80 is complicated. The problems concerning material flow from Building 80 are discussed in section 3.2.1.

### **3.2.1 Warehouse material flow**

Figure 7 shows the material and information flow between Building 80 and the Flow Line.



**Fig.7. Material and information flow between Building 80 and the Flow Line**

The current workflow and its communication system have several elements in the network. The main elements in the system are: the warehouse, the assembly bay, the testing bay, the shortage rack, the shortage list and the SAP system.

After material is pulled by the production supervisor using the kit codes, the material handler first picks the parts for the kits, and the kits are delivered by truck from warehouse to flow line approximately 12 times a day. When the material handler picks the parts for the kits, some parts might be out of stock at the time of picking. In such a case, the material handler records the shortage situation, but still picks and delivers the incomplete kits to the flow line. The missing parts will be delivered to the flow line once the warehouse receives those parts from the supplier.

However, when the incomplete kits are delivered to the flow line, no notification about the shortage is made to the flow line. When the operators find out some parts are missing from the kit, they write the shortage information on the shortage list to notify the material coordinator.

Also, when the out of stock parts are made available to the warehouse, they are at times delivered directly to the machine (path 2 showed in Fig.7) whereas other times they are delivered to a shortage rack (path 1 showed in Fig.7). Whether the parts will be delivered to the tool or the shortage rack depends on the operator who works at receiving area at the flow line. When the missing parts are delivered to the shortage rack rather than directly to the tool, no notification is made to the assembly bay. Thus, the operator needs to frequently check the shortage rack to see if the needed part has arrived (path 1 in Fig.7).

### **3.2.2 Testing bay material flow**

During module testing, the parts which fail need to be replaced, and are pulled by test technicians. There are several different paths of pulling and receiving the material. When the part need is not urgent, the test technician sends the request through the SAP system, and waits for the warehouse to deliver the parts to the testing bay. When the test technician needs the parts urgently, he or she will call the material coordinator and the coordinator will call a 'hotline' to request the warehouse to deliver the parts with the next scheduled truck (path (1) showed in Fig.7). At the highest level of urgency, the test technician will use the parts from the kits delivered to assembly, and make note of it on the shortage list to communicate this to both the material coordinator and the assembly operator (path (2) showed in Fig.7).

In either case, the test technician sends a request for parts through the SAP system (path (3) showed in Fig.7). Since there are three paths of communication, it is confusing for both material

coordinator and test technician. In the instance that the test technician chooses to get parts from the assembly bay, it causes delays to the upstream assembly process.

### **3.3 Testing Processes**

Close observations of the testing process revealed that the process had a lot of avoidable non-value added activity. Also, there are several tests done at the Supermarket to ensure the quality of the various sub-assemblies, which are repeated at the 90° module test bay. Currently, the first pass yield of the process is 0%. This means that no machine passes testing without having a quality incident of one form or the other, and all of them need rework to some extent. The sections below will talk about each of the following issues in more detail.

1. Hook-up and break-down time
2. Eliminating or reducing testing
3. Rework

#### **3.3.1. Hook-up and break-down time**

The process of connecting the machine to the test fixture and different outlets is called hook-up, and the disconnection of these after testing is called break-down. The hook up and break down processes can take up to 9 hours altogether. These 9 hours do not add any value to the machine but they are necessary steps. Investigating these steps in more detail and probing ways to do the same job in shorter time will have value for the company and reduce the lead time for the testing process.

### **3.3.2. Eliminating or reducing testing**

Certain sub-assemblies built in the Supermarket area are tested there before being forwarded to the Flow Line. Consider the example of the Quad 1, Quad 2 and Quad 3 sub-assemblies of the 90° module. The Quads 1, 2 and 3 pass a Gauss test in the Supermarket after being built and are then delivered to the Flow Line. After the 90° module is built and moved to the test bay, the same test is conducted at the 90° module test bay. Thus, the test procedure at the 90° module test bay seems redundant. Comparing the test procedures at the Supermarket sub-assembly area and the 90° test bay to identify differences can be beneficial. If there is no major difference, then the test procedure at the 90° test bay can be eliminated.

Also, the gas box assembly is common to both the 90° module and the Terminal module. For a 90° module, the gas box is tested in its sub-assembly zone, and then moved downstream. However, for the Terminal module, the gas box is tested after it is assembled with the Terminal module. If the gas box for the terminal could be tested earlier at the sub-assembly level, it will reduce the cycle time directly as the gas box testing could be done in parallel with the Terminal build process. Moreover, upstream testing of the gas box will reveal problems or quality issues earlier and it is easier to fix the problems at the sub-assembly level rather than after the gas box is assembled into the Terminal module.

### 3.3.3. Rework

Currently all the machines fail one test or the other, and need rework to some extent. Analysis of the quality notifications (QN) data revealed the top three reasons for testing failures of a 90° module and Terminal module as shown in table 3.

**Table 3: Top contributors to QNs filed for 90° and Terminal Modules**

<b>Module</b>	<b>Reason 1</b>	<b>Reason 2</b>	<b>Reason 3</b>
90° Module	Supplier: 39%	In-house manufacturing: 25%	Material Handling: 9%
Terminal Module	Supplier: 47%	In-house manufacturing: 23%	Miscellaneous: 7%

Also, many a time a part or sub-assembly fails during testing and has to be replaced. As mentioned in section 3.2.2 there are several different ways of receiving a failed part. Moreover, our analysis showed that a majority of the parts which regularly failed were not located close-by, but in Building 80, which is not located close-by. Every time an operator working in test bay needs a part replacement, he or she has to go through the complex process described in section 3.2.2. Therefore, the quality issue of a failed part followed by the material flow issues compounds these problems.

### **3.4 Materials Management**

Management of parts and inventory was found to have certain problems at strategic and operational levels. The main problems observed were as follows -

1. Material shortages
2. High work-in-process (WIP) inventory
3. Unscientific supply chain performance indicators

#### **3.4.1 Material shortages**

Material shortage is a common situation on the production floor and delays production to a large extent. Not all instances of shortage delay production because operators can work on different tasks of the module, and then returning to a process on part arrival. However there are some shortages which hold back production because these out of stock parts or subassemblies are crucial in the build process.

Several reasons are identified for material shortages. The biggest contributor of the shortages is unavailability of parts on time from the suppliers. While the uncertain demand and changing customer orders is a big driver of shortages, Varian also resists holding inventory to offset the variability. The company prefers carrying the least possible raw materials inventory. This is because of the nature of the market Varian operates in. Due to the cyclic fluctuations of the market, any large form of inventory can become a liability if the demand suddenly drops. Moreover, given the rate of technological change and design changes in this domain, there is a high risk of obsolescence associated with large inventories. Thus, for reasons of cost and obsolescence, the company policy is to have the least possible raw material inventory.

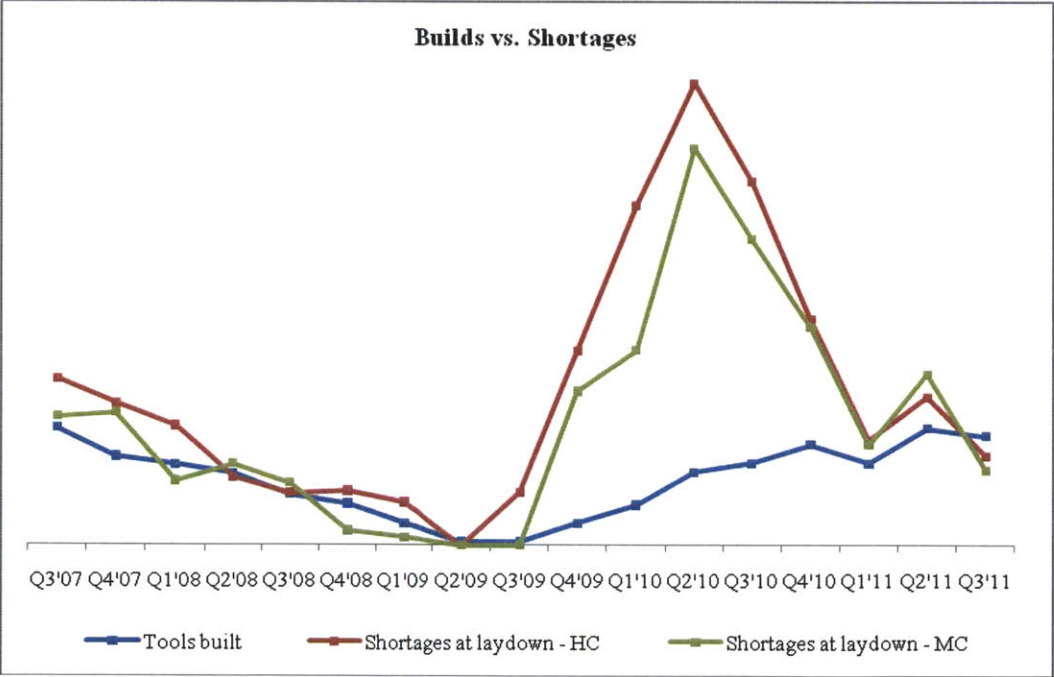
Based on the observations of production process over a period of 4 weeks, the instances of shortage and their duration were documented. This was meant to understand in first person how often the shortages occur, and how long a machine might be held up waiting for a part to arrive. These observations revealed that while all machines in the build stage face shortage of some form or the other, there are some parts which are out of stock more frequently and delay the build process far longer than other parts. Table 4 lists these parts and sub-assemblies, and how long the shortage situation existed on an average, based on observations over a period of 4 weeks.

**Table 4: Shortage instances observed on the 90° module and their duration**

Part / sub-assembly name	Number of tools which were waiting for this part	Average time the shortage lasted (days)
Beamline manipulator	3	6.66
Resolving assembly	2	6
Source chamber	2	9
D2 Harness (Japanese)	1	3
Dual N2 bleed assembly	1	4
Fiber optic harness	1	5
Flange ion	1	4
Japanese A.C Harness	1	8
Raceway Japanese B. L	1	8
Upper ground straps	1	3
XP Cooling kit	1	10

The Logistics department has a metric to measure shortages. Their metric, called ‘shorts at laydown’, measures the number of parts which are unavailable when required on the scheduled laydown date of the machine. The average number of shorts per laydown over the past 9 months for High Current tools is 29.11 parts and for Medium Current tools it is 29.55 parts. However,

this may not be the most accurate way of measuring the shortages and this metric will be discussed in detail in section 3.3.3. Nonetheless, it is a useful indicator of the occurrence of shortages. The shortage occurrences depend strongly on customer demand and how fast Varian’s suppliers can ramp up production to meet the demand. Varian has found it difficult to accurately forecast customer demand. Varian experiences cyclic production swings from 1 tool order per month to 30 tool orders per month within a period of 6 quarters. The number of instances of shortages is found to follow the rise and fall of demand. Figure 8 shows this. The Y-axis data have been removed for reasons of confidentiality.



**Fig.8. Shortages on High and Medium Current tools affected by demand Q3'07 to Q3'11**

The shortage of parts causes several problems on the production floor. Firstly, it delays the tool build process thereby causing a tool to spend longer time as WIP on the floor with no work being done on it. Tools which stay on the floor longer tend to be worked upon by more operators, and this carries the risk of quality issues. Finally, it leads to shipping delays to customer. The company’s supply chain score card reveals a 90% on-time tool shipment rating for tools shipped

over past 8 months. Thus, the issue of raw material shortages is an important one and is the one of the focal points of this thesis.

### **3.4.2 High Work-In-Process (WIP) inventory**

When there is a material shortage that hinders the progress of assembly, the operators try to work around the shortage by working on another tool which does not have a shortage. In such a situation, the lead time of assembly is lengthened because of material shortage. As a result, more machines need to be laid down in the assembly area to achieve the required throughput rate. This leads to more space being taken up and more work-in-process (WIP) inventory. Moreover, greater the number of machines being assembled, greater is the instance of shortages as the machines will often be waiting for the same parts or subassemblies.

First person observations were performed to document the WIP at different instances of time, and whether at that instant the tool was being worked upon by one or more operators or whether it was idle. The team prepared a spreadsheet in which to note down these observations. This is shown in Fig.9.

In the figure, every row represents the WIP situation of the 90° module line. The first 3 columns show the time at which the observation was made. The next column denotes which shifts were at work at that time. Each cell with a 6-digit machine number indicates that a machine is laid down in that bay on the shop floor. The different colors are meant to give a visual indication of the status of the machine. The key for the colors is as follows –

	0% (empty spot or just laid down)
	WIP - 1 person working
	WIP - 2 persons working
	WIP - 3 persons working
	WIP - NO person working
	Tool build complete

90 degree line										
Date	Day	Time	Shift	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	
6/3/2011	Fri	10:45 AM	1	149016	149015	137899	137898	137897	137887	
6/6/2011	Mon	10:15 AM	1 + 4	149016	149015	137899	137898	137897	137887	
6/6/2011	Mon	3:30 PM	2 + 4	149016	149015	137899	137898	137897	137887	
6/7/2011	Tue	10:00 AM	1	149016	149015	137899	137898	137897	137887	
6/8/2011	Wed	10:00 AM	1	149016	149015	137899	137898	137897	137887	
6/8/2011	Wed	4:15 PM	2	149016	149015	137899	137898	137897	137887	
6/9/2011	Thu	8:30 AM	1	149016	149015	137899	137898	137897	137887	137900
6/10/2011	Fri	11:00 AM	1	149016	149015	137899	137900	137907		
6/10/2011	Fri	2:30 PM	2	149016	149015	137899	137900	137907		
6/11/2011	Sat	10:00 AM	4	149016	149015	137899	137900	137907		
6/11/2011	Sat	10:15 AM	4	149016	149015	137899	137900	137907		
6/11/2011	Sat	10:30 AM	4	149016	149015	137899	137900	137907		
6/11/2011	Sat	2:10 PM	4	149016	149015	137899	137900	137907		
6/13/2011	Mon	8:30 AM	1 + 4	149016	149015	137899	137900	137907		
6/13/2011	Mon	1:30 PM	1 + 4	149016	149015	137899	137900	137907		
6/14/2011	Tue	11:00 AM	1	149016	149015	137899	137900	137907		
6/15/2011	Wed	11:30 AM	1	149016	149015	137899	137900	137907		
6/16/2011	Thu	10:30 AM	1	149016	149015	137899	137900	137907		

Fig.9. Snapshots of WIP inventory for the 90° module

A cursory look over of the figure shows that very often an assembly bay contains a tool but the tool is not being worked upon at the instant observed

There are many problems associated with high WIP. Firstly, having several tools on the floor at the same time requires more space to be devoted for the build area than warranted for by customer demand. Secondly, when a tool is in the WIP stage, a customer may make changes to the original machine order. Raykar's thesis [9] explains this issue in full detail.

### **3.4.3 Inaccurate supply chain performance indicators**

Varian's Logistics department is responsible for managing the supply chain, and it has some performance indicators against which their performance is measured. Two main measures related to shortages are of most concern here:

1. Shorts at laydown
2. Supplier on time to need

These performance indicators are not very accurate, and do not reflect the real state of shortages experienced on the shop floor. Raykar's thesis [9] explains these two measurements and their issues in full details.

### **3.5 Summary**

The issue of unnecessary non value added operations mentioned in section 3.1 is considered to be one of the main issues the company is facing, and it needs to be addressed. Since eliminating waste is one of the main steps towards building a lean manufacturing environment, the focus of this thesis will be to recommend solutions to reduce the unnecessary non value added operations such as

1. Parts Searching Process
2. Repetitive kitting and auditing

The subject of shortages and tackling the supply chain policies was the other area of the focus of our team. Raykar's [9] and Chen's [11] theses look at the procurement policies and suggests corrections in the stocking policies to reduce the instance of shortages.

The other problems mentioned in this section were presented to the company, so that actions could be taken on them in the future.

## **4. Review of theoretical background**

This section gives an overview of the pertinent theoretical work published in the areas of lean manufacturing and supply chain planning.

A lot of technical literature has been published on the subject of lean manufacturing. One of the most rigorous analysis is contained in the highly influential book ‘The Machine That Changed the World’ [12] by James P. Womack, Daniel T. Jones and Daniel Roos. Based on studies of factories worldwide, with a special focus on the Toyota Motor Corporation, the book discusses in detail the basic concepts of lean manufacturing, and its broad applicability in manufacture of different products. The methods discussed herein were useful in NVA and waste identification.

Value Stream Maps are a useful lean manufacturing tool to graphically plot the flow of material and information starting from the suppliers, through the internal manufacturing processes and ending with the customer. This technique originated at the Toyota Manufacturing Company. ‘Learning to See’ by Rother and Shook [13] is a guide book which explains how to effectively use VSMs.

The value stream map (VSM) gives a look at the big picture and not just individual processes. Value stream mapping provides an opportunity to discover the root causes of wastes and improve the whole process rather than optimizing individual steps.

Value stream maps have three stages of development.

**Current state VSM:** It shows the process in the existing state and includes the entire process including the non-value added activities. It requires several hours of observation to map a representative VSM. Detailed observations and drawing spaghetti charts were the key for the team to be able to map the process.

**Ideal state VSM:** It shows the process in the perfect condition, which could be almost impossible to achieve practically. This map would show how the process would look like in a perfect setting if nothing went wrong or there was no process variability to deal with, and the resultant benefits.

**Future state VSM:** The purpose of the whole VSM process is to identify the waste and eliminate them by implementation of the improvements that would reduce these wastes. The future state VSM is drawn after comparing the current state VSM to the ideal state VSM. The future state VSM chooses the most practical goals from the ideal state VSM, shows which improvements can become a reality in a short period of time, and the resultant benefits.

Rother and Shook [13] explain how to draw current-state, future-state and ideal-state VSMs. This informed the methodology towards the project.

In lean manufacturing philosophy, inventory is one of the 7 wastes which are commonly observed at most production facilities. The Toyota Production System (TPS) emphasizes single piece flow wherein only one product is worked upon at a time [14].

5S is a workplace organization methodology which gets its name from five Japanese words - Seiri, Seiton, Seiso, Seiketsu and Shitsuke. [16]. The 5S concept was built-up by Hiroyuki Hirano with his approach to production systems. [17]

The English translation of the 5S methodology is: **Sorting, Straightening, Systematic cleaning, Standardizing, and Sustaining**. 5S method is one of the first steps toward Kaizen process improvement. Each concept is explained here briefly.

**Sorting:** It involves eliminating all unnecessary parts, tools, and instructions. Operators are expected to go through all tool racks, materials, and instructions on the shop floor, and eliminate all the unnecessary ones. The aim is to keep only those tools and materials that are actually being used, and prioritizing them as per requirements. All the tools and equipment required by the process should be in easily-accessible places.

**Straightening or setting in order:** This involves labeling all the tools and equipment, and having a proper place devoted for them. This can save time for operators. The location for each tool rack should be picked carefully so that the non-value added time that an operator spends in motion is reduced. Items should be arranged in a way that provides efficient work flow. i.e. one which minimizes work movements and motions.

**Systematic cleaning:** Workspace and all equipment should be cleaned, and maintained tidy and organized. At the end of each shift, the operators are expected to clean the work area and ensure that everything is restored to its marked place. This makes it easy to know where different tools

are stored, and ensures that everything is where it belongs. Spills, leaks, and other messes also then become a visual signal for equipment or process steps that need attention. A key point is that maintaining cleanliness should be part of the daily work – not an occasional activity initiated when things get too unclean.

**Standardizing:** Work practices should be consistent and standardized. All work stations for a particular job should be identical. All employees doing the same job should be able to work in any station with the same tools that are in the same location in every station. Everyone should know exactly what his or her responsibilities are by adhering to the first 3 S's.

**Sustaining the discipline:** This implies maintaining and periodically reviewing the set standards. Once the previous 4 S's have been established, they become the new way to operate. The periodic reviews are necessary to ensure that the focus is maintained, and sub-standard practices do not develop. At the same time, improvements to the standards should be welcomed. When an issue arises such as a suggested improvement, a new way of working, or a new tool, the first 4 S's are reviewed, and a change for the better should be made. As an example, with the proposal to improve the raw material presentation, the 4S's are being considered as important factors in developing the new system.

# **5. Methodology**

## **5.1 Preliminary analysis**

### **5.1.1 First person observations**

The first step in the process of identifying areas for process improvements is performing micro level observations. The team spent over 4 weeks observing the build and test processes to identify the non-value added activities that occur at each step. The operator's actions were compared to the steps given in the work procedures. If the operator's action did not match the procedure, the reason for it was investigated.

A useful method of identifying unnecessary operator motions is by drawing a spaghetti chart. The chart gets its name from the way the graphic typically looks like after documenting a couple of operator movements. Spaghetti charts were drawn to document wasteful motions i.e. to see how much time operators wasted searching for tools and parts stored at different locations on the shop floor.

In addition, the following observations were recorded on a daily basis:

- Shortages on each machine: To track the amount of time each machine stays idle and waits for parts to arrive.
- Work in Process (WIP): To track how many machines are sitting on the shop floor, how many are being worked upon, and how many are idle.

- Cycle Time: To track the actual cycle time for each machine and compare it with the planned cycle times.
- Quality issues: To investigate the reasons that rework occurs on each machine at the test bay.

The company log book which contains the work procedures was used as a reference to break down the lengthy assembly and testing processes into smaller segments. SAP software which is the company's Enterprise Resource Planning (ERP) system was used to gather operational data on cycle times, quality issues, material movements, scheduling and procurement history.

### **5.1.2 Value Stream Maps**

The preliminary observations help map out the process and identify the non-value added activities that can be eliminated. Value stream mapping was used as a graphical tool to document the material flow and all the details about each process. The value stream maps cannot be shared here because they contain confidential data. However, the main findings derived from them are presented here. The guidelines for constructing a VSM specific to Varian are also discussed.

#### **5.1.2.1 Findings from Current State VSM for the 90° module**

The main findings from the current state VSM for the 90° module are:

1. The lead time for the build and test processes combined, including delays due to shortages is found to be 251.9 hours. However, the actual time spent working on the tool is only 66.5 hours.

2. The main reasons why the cycle time is so distended are: Material shortages; NVA time spent looking for parts or hardware; and performing non-assembly tasks over-and-above those given in the work procedures.
3. Material shortages are found to cause lead time to increase by up to 4 days. The main shortages are found to occur on the Resolving Assembly, the Source Chamber, the Beamline Manipulators and the Q3 lens.
4. Operators frequently move around the shop floor looking for tools, or parts needed for assembly. It is estimated that up to 4 hours are wasted in the total build procedure collecting parts or hardware from different locations on the floor.
5. Non-assembly tasks observed being performed by operators take the process longer than expected. The list of such tasks includes operations like filing, grounding or sanding imperfect parts from suppliers; un-packing and de-trashing parts received from suppliers; and making kits and auditing those received from the warehouses. The team's estimate is that up to 2.5 hours are spent doing non-assembly tasks.

#### **5.1.2.2 Findings from Current State VSM for the Terminal module**

The main findings from the current state VSM for the Terminal module are:

1. The lead time for the build and test processes combined, including delays due to shortages is found to be 143.6 hours. However, the actual time spent working on the tool is only 101 hours.

2. The main reasons why the cycle time is so inflated are: Material shortages; NVA time spent looking for parts or hardware; and performing non-assembly tasks over-and-above those given in the work procedures.
3. Material shortages are found to cause lead time to increase by 1 day at a minimum. The main shortages are found to occur on the Source Chamber and the Gas Box sub-assemblies.
4. The time spent by operators searching for parts or hardware is estimated to be about 4 hours.
5. Operators perform such non-assembly tasks as – typing and printing out labels (2 hours per tool); un-packing and de-trashing parts received from suppliers; and making kits and auditing those received from the warehouses. In total, an estimated 5 hours are spent doing non-assembly tasks.

#### **5.1.2.3 Guidelines for Ideal and Future State VSMs**

For constructing an Ideal state VSM, the following assumptions were made.

1. No amount of time spent searching for parts. It is assumed that parts are easily available to the operators when needed.
2. There are no shortages of materials to the shop floor. Thus, the waiting time attributed to shortages is taken out of the lead times shown in the current state VSM.
3. It is assumed that there is no time spent doing rework.

4. It is assumed that operators do not spend time on non-assembly tasks such as printing labels, auditing or making kits or minor rework to incoming parts.

For constructing a Future state VSM, the following assumptions were made.

1. The recommendations presented here deal with improving the presentation of raw materials to the shop floor. This is intended to save the time spent looking for parts, or hardware. However, it is not possible to completely eliminate this. So, the time spent doing this is reduced from current state maps, based on heuristic data.
2. The recommendations presented in Raykar's thesis [9] and in Chen's thesis [11] should lead to reducing the problem of material shortages. But it is acknowledged that shortages cannot be entirely eliminated, and may occur as an operational mishap. Nonetheless, an estimate of how long a shortage may last is made and the delay is included in calculating the lead time.
3. It is assumed that rework does occur and requires as much time as on the current state VSM.
4. It is assumed that operators do not spend time on non-assembly tasks such as printing labels, auditing or making kits or minor rework to incoming parts.

The outcome of the ideal and future state maps is discussed in section 8.4.

### **5.1.3 Analysis of Data from Databases**

The SAP and Lotus Notes databases are the source of historical and factual information of the operations. This data was found useful in the observation stages as well as while doing analysis for verifying our hypotheses.

#### **5.1.3.1 Data for Value Stream Maps**

While value stream maps are useful to document first hand observations, these alone might not give the complete and accurate map of the process. A more representative and accurate source of information is the production history data from the databases. From these databases, actual data about cycle times measured over extended periods of time was found.

## **5.2 Improved Efficiencies in Raw Material Presentation Methodology**

The following steps were followed in developing an improved system for raw material presentation:

1. Review the existing system
2. Grouping parts as per build procedures
3. Find gaps in the machine BOM
4. Re-group parts by following the 5S methodology

The first step was to review the current kit coding system. As mentioned in Section 2.1.3 parts are grouped by kit codes and pulled from the warehouses by the shift supervisor. Currently the kits are not organized, and each kit may contain up to 300 parts. The kits which are pulled arrive on the Flow Line in bins and boxes without specific labels as shown in Fig. 10.



**Fig.10. Current kit code system**

After reviewing the current system, it was found some of the kits include parts from different steps in the log book as well as different day of the assembly process. As mentioned in Section 3.1.1, the assembly of both the 90° module and the Terminal module contains 10 steps, each of which contains many sub-steps. In total, both assembly procedures contain hundreds of sub-steps. The work instructions for these procedures are documented in the company's log book system. In the current kitting system, one kit can include parts from different steps of a log book which is not efficient. Because it is not clear for the operator which kit to look for when he or she is looking at a specific step in the log book. Therefore, grouping parts per procedure step was one of the main factors to be considered.

After identifying all those parts and kits, the next step was to go through a complete tool BOM in order to identify any parts with no kit code. As mentioned in Section 2.1.1, a BOM is a list of all the parts required for assembly of a tool. BOMs are hierarchical in nature with the top level

representing the complete tool with PBO line items below. As mentioned in Section 2.1.1 PBO is a very detailed machine order. One level below the PBO line items are all the parts and sub-assemblies. This kind of BOM is known as Indented BOM which was helpful in order to group the parts per sub assembly step. At this stage after reviewing a complete tool BOM, all the parts without kit codes were identified. In the new kitting process an appropriate kit code will be assigned for all the parts. It is more systematic if all the parts have kit codes and follow the same pulling procedure to be present on the shop floor.

The final step involved grouping all the parts in a logical way as per the build procedure steps, and following the 5S methodology. The main parameters that were considered while breaking down the kits into smaller groups are listed below.

Ideally, each kit:

- is specific to a procedure and has parts from a single warehouse
- is delivered Just-In-Time (JIT) as per requirement
- is sealed
- is labeled properly and is easy to identify
- contains a BOM which indicates any shortages

Each parameter and the actions taken for each will be explained in detail in Chapter 6. Figure 11 shows the 5S methodology principles and Fig. 12 shows how these principles were considered in the suggested implementations.



**Fig.11. 5S methodology**



**Fig.12. 5S methodology consideration**

## **6. Raw Material Presentation Analysis**

### **6.1 Problem overview**

As mentioned in Section 3.1.2, currently the kits are not organized, and each kit may contain up to 300 parts. The kits which are pulled arrive on the Flow Line in bins and boxes without any specific label. Thus in the current situation, the operators need to look through all the bins and boxes in order to find a part among all the kits which got delivered on the line. Additionally, since there is no shortage notification system with the delivered kits, the operators need to look in all the bins before detecting that the kit is incomplete. This process can take a long time and no value is added during the searching process. It can be eliminated if there is a proper part organizing system, and improved communication about material delivery.

### **6.2 Proposed Logic for Kitting of Parts**

As mention in Chapter 4, there are 5 primary steps in the 5S methodology: Sorting, Straightening, Systematic cleaning, Standardizing, and Sustaining. These 5 factors were the primary guideline to group the parts into kits. The operators' inputs were also taken so that a holistic solution would be developed. The main purpose was to make the operators working time more productive, and hence their feedback was important. The main parameters that were considered while breaking down the kits into smaller groups are listed below as mentioned in Section 5.2.

Each kit:

- is specific to a procedure and has parts from a single warehouse
- is delivered Just-In-Time (JIT) as per requirement
- is sealed
- is labeled properly and is easy to identify
- contains a BOM which indicates any shortages

These parameters are discussed in detail below.

### **6.2.1 Precise kitting**

The best way to group parts in a kit is to group them as per the build procedure steps. Some of the steps include several parts which could be segmented into smaller sections, considering their storage location. Section 6.2.3 deals with this topic in detail.

As discussed in section 5.2, the methodology behind grouping was as follows: the first step was to review the current kit codes and understand it. After reviewing the current system, it was found some of the kits include parts from different steps in the log book as well as different day of the assembly process. After identifying all those parts, the next step was to go through a complete tool BOM (about 6000 parts) and identify all the parts without kit codes. Lastly, group all the parts in small groups in a logical way per procedure steps. Smaller kits will increase the chance that a kit is complete at the time of delivery. This also aligns with Raykar's project [9] to reduce WIP on the flow line due to shortages.

This method of breaking down the kits can help reduce the excess inventory on the kits rack. In order to get full advantage of the break down of the kits into smaller sizes, the production

supervisor needs to release the kits more frequently. Currently, the supervisor releases the first half of the kits 24 hours before the build start date and the second half on the following day. The idea here is to have smaller kits which deliver more frequently. Kits can be split into 4 different groups, which correspond to a 4 days build plan. Each group will contain several kit codes and will be color coded to be recognized from the other groups as shown in Fig.13. This also works as a buffer in the event of a material or kit shortage. This is because, when a shortage occurs, the operators work around it by doing a different assembly task.



Fig.13. Color coding

### 6.2.2 Just-In-Time (JIT)

Just in Time (JIT) is one of the pillars of the Toyota Production System. It is a production strategy which leads to improved returns on investment as it focuses on reducing in-process inventory and associated carrying costs [15]. The concept of JIT is highly applicable at Varian. It is envisioned that under this system, the warehouses prepare and stage the kits for a tool a few days in advance of a machine laydown. However, kits which can be carried on 1 or at most 2 carts are delivered at a time to the production floor, as per need. This method will help to have a cleaner work space in accordance with the 3<sup>rd</sup> S – Systematic Cleaning – from the 5S methodology.

### 6.2.3 Kitting location

There are 2 factors which need to be considered when deciding the point of origin for a kit –

1. Storage location of constituent parts
2. Failure and replacement frequency of the parts

#### 6.2.3.1 Storage location of constituent parts

As mentioned in Section 6.2.1, the location of the parts needs to be considered when grouping them into a smaller kit in order to minimize the material handler's picking time. The idea here is to pick most of the parts if not all from the same storage area as shown in Fig.14. This is the next phase for this project and was brought up to the manufacturing team group attention.

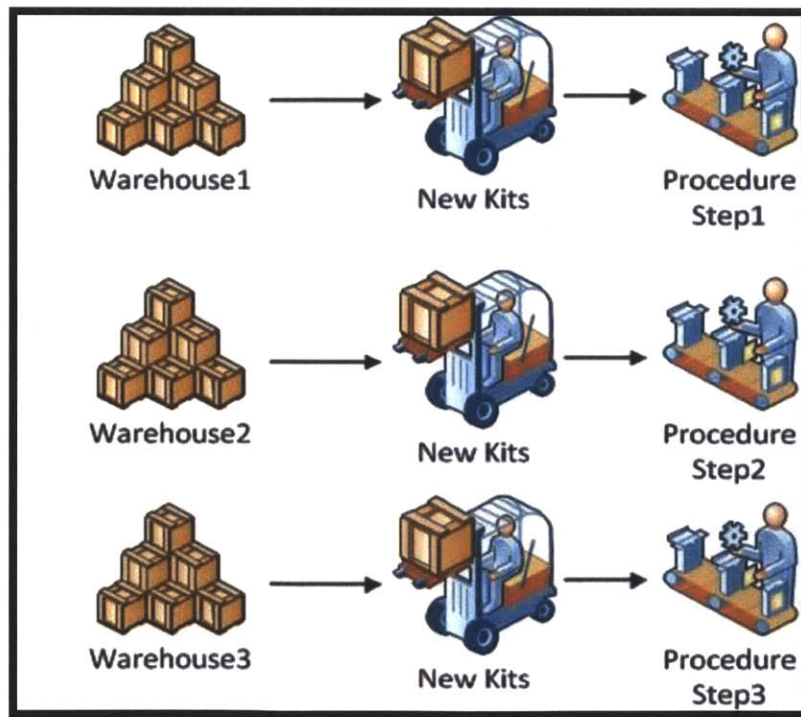


Fig.14. Localized kitting at a single warehouse

### 6.2.3.2 Failure and replacement frequency of parts

As mentioned in Section 3.3.3 currently all machines fail one test or the other and need rework to some extent. Many times a part or sub-assembly fails during testing and has to be replaced. As mentioned in section 3.2.2 there are several different ways of receiving a failed part. As shown in Table 5, majority of the parts which regularly failed were located in Building 80, which is not in close proximity to the test zone. Every time an operator working in test bay needs a part, he or she has to go through the complex process described in Section 3.2.2.

**Table 5: Most frequently failed parts**

<b>Material Description</b>	<b>Count</b>	<b>%</b>	<b>Storage Location</b>
INTERFACE ASSY,PNEUMATIC,BEAM	38	0.10	MOD
CURRENT MONITOR,SET UP CUP	13	0.03	WH
INTEFACE ASSY,VACUUM PUMP	11	0.03	MOD
CONTROLLER,90 DEGREE MAGNET POWER SUPPLY	10	0.03	WH
INTERFACE,ANALOG/DIGITAL,I/O MK II	10	0.03	WH
CABLE ASSY, FIBER OPTIC, LL2015, 90 MODU	8	0.02	GL
FLOW SWITCH ASSY,.15 GPM	8	0.02	GL
FEEDTHRU, MANIPULATOR	7	0.02	GL
POWER SUPPLY,QUAD 2,40V,38A	7	0.02	WH
PS CONT,D1 SUPP,W/SELF GLITCH CHECK	7	0.02	WH
GAUGE,MINI,CONVECTRON,W/PROCESS CNTRL	6	0.02	SMKT
PCB,DIGITAL I/O	6	0.02	GL
VALVE,AIR ACTUATED,VCR,1/4 FEMALE	6	0.02	SMKT
X',POWER SUPPLY, SUPPRESSION, -25kV/10mA	6	0.02	WH
POWER SUP,MAGNET,10.2kW,50VDC/250A	5	0.01	MOD
RACEWAY ASSY, 90 MODULE, ELECTRONICS RAC	5	0.01	WH
SOURCE SUPP. PS CONTROLLER W/PGF	5	0.01	WH
BLOCK,COOLING,RH,VARIABLE APERTURE,2.50	4	0.01	WH

It is recommended that the most frequently failing parts should be located in the MOD storage area, which is very close to the testing area.

#### **6.2.4 Visual BOM**

In order to minimize the part searching process time, all the bins should be clearly labeled. Color coding can be useful as well since it will be a visual way to locate a kit or spot an error. Four colors can be used, one color for each day of the build. The procedure should also contain color symbols relating the kit to the procedure. While the operators may not follow the build sequence because of shortages or other reasons, the color coding is still useful in locating the correct kits and parts. Training new operators will also be easy with this system because of the simplicity and intuitive nature of the system.

Each kit should include the BOM for that particular pick list, and clearly mention if there is any material shortage in the kit. There are two options proposed to achieve this task. One way is to make a copy of the pick list that the material handlers use after picking the parts. If there is any shortage within that kit, the material handler should use a red sticker as a marker to notify the operator on the floor that this kit is not complete. The other option is to make a new template for the material picking process. The template should have the following fields:

1. Tool number
2. Kit code number
3. Procedure step name and number

4. Shortage indication
5. Part number
6. Quantity required
7. Quantity picked

An example is shown in Fig. 15. This option is recommended since it builds upon the existing system and improves it. It also does not require any changes to the SAP database system, and thus can be rapidly deployed.

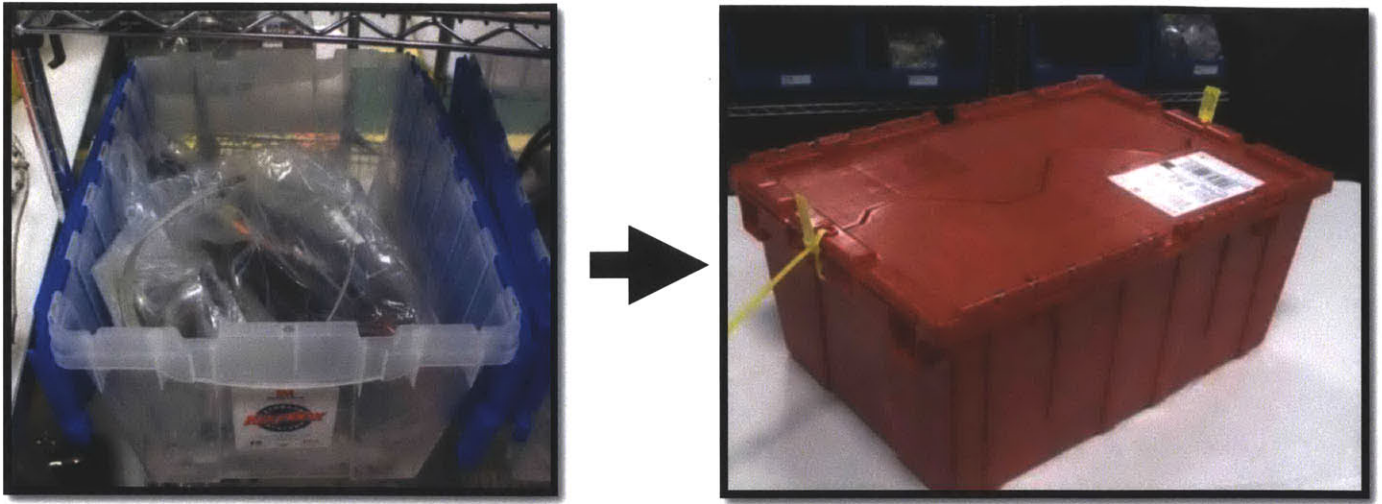
Tool # : XXX	Kit Code : XXX		Procedure Step
Shortages	Yes	Y	
	No		
Part number	Quantity required		Quantity picked
<div style="border: 1px solid black; padding: 10px; display: inline-block;"> <b>Pick list</b> </div>			

**Fig.15. Material pick list sample**

### **6.2.5 Sustaining the process**

One of the main outcomes of this project is to minimize the number of kits with shortages delivered to the shop floor. The idea is to change the culture to “Only pick a Kit when it is complete”. When a kit code has been released into SAP, SAP will check for availability of all the parts in that pick list. If there are any shortages it will notify the material picker ahead of the time. Material handlers should pick the kits that are complete, before picking a kit which has shortages to avoid passing on the shortages to the shop floor.

Currently it is common for an operator with an incomplete kit to borrow parts from the kit of a neighboring machine. The operator working on the neighboring machine may not be notified about this, and this leads to confusion and makes part tracking difficult. Unless the production supervisor takes the given part from the certain tool due to priority in shipping, this should not happen at all since it adds to the confusion and delay on the shop floor. It is beneficial to seal the kit after it has been picked at the warehouse. This process can be as simple as using a zip tie and sealing the bin as shown in Fig.16. When the operator is ready to start a process, he/she can walk to the rack, grab the corresponding bin and start the procedure. Having the bins sealed will avoid misplacing of parts on the shop floor, and it will discourage borrowing of parts between machines.



**Fig.16. Sealed completed kit**

#### **6.2.6 WIP information board**

As a form of communication, it is recommended that an information board be installed next to each tool. Information about the tool, its build status and material shortages should be carried on the board. The following parameters give all the necessary information about the build status -

1. Tool number, type and customer
2. Laydown date and shipping date
3. Tool owner/operator's name
4. Material shortages, and name of responsible person
5. Known quality issues

Visual indicators are recommended to be used to give instant information about the status of the tool, similar to the system showed in Fig.7. Red tags or stickers should be used to indicate a shortage or quality issue, with the name of the responsible person. This information board will

make the problems visible. This is the first step in moving to a culture of Kaizen, and starting Kaizen events.

### **6.3 Cost and Benefit Analysis**

The benefits associated with the recommended raw material presentation are as follows –

1. Improved presentation and completeness of kits reduces the NVA time operators spend searching for parts. As discussed in section 5.1.2, from the current state VSM, it was found that 4 to 5 hours are spent per tool searching for parts. Thus, the proposed system will reduce the cycle time by 4 to 5 hours.
2. The workplace will be clean, organized and easy for operators to work in. Everything will be labeled and have a place.
3. The visual BOM as well as WIP information board help to make the problems obvious. Making problems visible is the first step in taking Kaizen actions to improve the process.
4. The logic proposed for kitting ensures that all parts of a kit are stored at the same warehouse. This makes the excess movement of parts and people between warehouses redundant. It also reduces the amount of time required to build a complete kit.
5. The second aspect of the kitting logic discussed in section 6.2.3.2 considers the frequency of part failure in testing. By moving the frequently failing parts to the indoors MOD storage area, the time wasted in waiting for a replacement part is sharply reduced.

6. The proposed system leads to a culture where complete kits are expected to be a norm, rather than an exception. It also reduces part borrowing between machines, and simplifies part tracking.

The following costs are associated with the implementation of the recommended solutions

1. The project recommends more kits which will require more reusable bins and boxes to be deployed. It is recommended that bin sizes be chosen in accordance with the size of the kits, instead of the existing single size binning system.
2. Developing a new template for the material picking process that has boxes for all the visuals that are necessary for the operators on the shop floor.
3. Cost of purchasing white boards to install next to each WIP on the shop floor.
4. A drawback of this project is that it can generate more work for the material pickers at the warehouse since the number of kits has been increased for the same number of parts. However, since each kit is smaller than before, it is estimated that handling the new kits will be easier than before

## **7. Conclusion and Future work**

### **7.1 Conclusion**

In conclusion, improved presentation and completeness of kits will help to reduce the NVA time operators spend searching for parts by 4 to 5 hours. The workplace will be clean, and organized for operators. Everything will be labeled and have a place. The visual BOM as well as WIP information board will help to make the problems obvious.

The logic proposed for kitting ensures that all parts have a kit code and also all the parts from the same kit are stored at the same warehouse. This makes the excess movement of parts and people between warehouses redundant.

The proposed system can lead to a culture where complete kits are expected to be a norm, rather than an exception. It also reduces part borrowing between machines, and simplifies part tracking.

### **7.2 Future work**

#### **7.2.1 Inventory locations at the warehouse**

As the next phase for this project, a closer look at the inventory locations in the warehouse is recommended. The inventory can be moved around so that most of the parts in a kit are located in the same storage area in order to reduce the material picker's moving time. It is also

recommended that the most frequently failing parts be transferred to MOD storage area, which is very close to the testing area.

### **7.2.2 Other Recommendations**

Operational problems which were discovered as part of the team's first person observations were discussed in section 3. These observations were presented to the company as future actionable items.

## **7.3 Summary of Ideal and Future State Value Stream Maps**

The findings from the current state VSM and guidelines for constructing the ideal and future state VSMs were presented in section 5.1.2. Based on these and the recommendations presented in this thesis, ideal and future state VSMs were constructed. While the maps cannot be included in the thesis because of confidentiality concerns, the production lead times are scaled and summed up in table 6 below.

**Table 6: Estimated production lead times**

	Current State	Ideal State	Future State
90° Module	1.0000	0.2706	0.5366
Terminal Mod	1.0000	0.6963	0.8587

Thus, it is assessed that the production lead time could be reduced by 46.34% for the 90° module, and by 14.13% for the Terminal module over the Current State, by adopting recommendations contained in this thesis, as well as those in Raykar's [9] and Chen's [11]

theses. These are significant savings, and the methods of achieving these savings were presented to Varian.

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