Lean Manufacturing in a Mass Customization Plant: Improvement of Kanban Policy and Implementation

by

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Abstract

This thesis documents the application of the principles of lean manufacturing and supply chain planning at Varian Semiconductor Equipment Associates. Varian is a manufacturer of ion implantation machines, and supplies and services equipment for most of the leading semiconductor manufacturers. The demand for the company’s products is uncertain. The products are customizable, and the production schedules change from day to day to comply with customer requests.

In situations where variability – whether in product features or logistics, use of lean manufacturing techniques like Value Stream Mapping and Waste Elimination helped to highlight the main problems. The main problem at Varian was the chronic part shortage from suppliers. Further investigation revealed improper supply chain and inventory management. Specifically, the Kanban policy is found to have a majority impact of current shortage situation.

Lean manufacturing principles and supply chain planning were implemented to analyze and remedy chronic part shortage. Improper supply chain and inventory management practices were identified. A new Kanban policy was used to improve the shortage situation. Recommendations included a shorter lot size review period, larger safety factor and a new lot size decision making strategy based on historical demand.

Thesis Supervisor: Stephen C. Graves
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1. Introduction

This section serves to deliver an overview of the semiconductor equipment industry, background information about Varian Semiconductor Equipment Associates and the company needs at the point at which the project was conceived. The capital intensive nature of the semiconductor equipment is explained first. The effect on the manufacturing operations of the relationship between a chipmaker like Intel and an equipment maker like Varian is described briefly in the first section. 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 to us 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 like 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 and all customer requirements. 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, MA 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 viz. High Current (HC), Medium Current (MC), High Energy and Ultra High Dose or VIISTA PLAD. The ‘200 mm’ or ‘300 mm’ 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
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

<table>
<thead>
<tr>
<th>High Current (HC)</th>
<th>Medium Current (MC)</th>
<th>High Energy</th>
<th>Ultra High Dose (PLAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIISTA HCP</td>
<td>VIISTA 810XP</td>
<td>VIISTA 3000 XP</td>
<td>VIISTA PLAD</td>
</tr>
<tr>
<td>200 mm</td>
<td>200 mm</td>
<td>200 mm</td>
<td>200 mm</td>
</tr>
<tr>
<td>VIISTA HCP</td>
<td>VIISTA 810XP</td>
<td>VIISTA 3000 XP</td>
<td>VIISTA PLAD</td>
</tr>
<tr>
<td>300 mm</td>
<td>300 mm</td>
<td>300 mm</td>
<td>300 mm</td>
</tr>
<tr>
<td>VIISTA HCPv2.0</td>
<td>VIISTA 900XP</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>200 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIISTA HCS</td>
<td>VIISTA 900XP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 mm</td>
<td>300 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
number of scans the beam performs upon the wafer. Automated control over these parameters is achieved by means of the control system. It 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.

![Figure 1: The modules of a Varian ion implanter machine](image)

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].
At this juncture, the company wanted to meet the growing demand not by adding direct labor or making a capital investment to expand their facilities, but by weeding out the inefficiencies in their operations. Specifically, the company wanted us 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 the 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 items.

A Production Build Order (PBO) is a very detailed machine order. It is used by the operators to know which 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 1200 parts, it is difficult 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 he expects them to be used, 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. The modules each require about 15 kits. 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. Daneshmand’s thesis [9] addresses in detail the problems associated with kit codes, and proposes some solutions.

### 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 to lay down, and on which date, subject to last minute scheduling changes and parts availability.

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. Then onwards 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, and several hundred more in shipping. Presently, about 75% of the customer orders follow 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. (See if this is required since the shortages project may end up targeting all zones). Figure 3 depicts the production areas and the warehouses at Varian’s Gloucester facilities.
Table 2: Production areas and their tasks

<table>
<thead>
<tr>
<th>Zone name</th>
<th>Work done</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supermarket (SMKT)</td>
<td>Building and testing different sub-assemblies which are installed in the module assembly downstream</td>
</tr>
<tr>
<td>Flow Line</td>
<td>Building and testing of the 90° and 70° modules for the High Current machines</td>
</tr>
<tr>
<td></td>
<td>Building and testing of the Beamline and Terminal modules for the Medium Current Machines</td>
</tr>
<tr>
<td></td>
<td>Building and testing of the Gas Box and Facilities modules</td>
</tr>
<tr>
<td>Universal End Station (UES)</td>
<td>Building and testing of the Universal End Station module for both High and Medium Current Machines</td>
</tr>
<tr>
<td>Clean Room</td>
<td>Assembles tools for Full Build machine orders</td>
</tr>
<tr>
<td>Air Shower</td>
<td>Modules are disassembled, cleaned and wrapped</td>
</tr>
<tr>
<td>Shipping Area</td>
<td>Final inspection, packaging and crating</td>
</tr>
<tr>
<td>Receiving and shipping docks</td>
<td>Receiving of parts from warehouse, suppliers, and dispatching machines to customers</td>
</tr>
</tbody>
</table>
2.2.2.1 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 as 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 namely Building 80 or Warehouse, Building 70, Building 5 and MOD storage area. Building 80 carries inventory of relatively small parts required on daily or hourly 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 and the delivery date, 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 material shortages which was found to be the biggest problem. The rest of the thesis will be devoted to documenting this problem and testing the proposed solution.

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

1. Unnecessary Non-Value-Added operations
2. Inefficient Communication of Material Flow
3. Testing Procedure
4. Materials Management

Among all the problems stated in this section, the issue of shortages is considered by our team and Varian’s production group as the biggest hurdles limiting Varian from reaching theoretical capacities. The focus of this thesis will be to recommend solutions to reduce the instances of shortages. Thus, to summarize, the problems which will be addressed by this thesis are –

Improvement of Kanban Policy and its' implementation

Kanban policy which meant to efficiently reduce inventory and shortage problem now actually caused more shortages in the company. Thus, an investigation of the problems with current Kanban policy and improvement of strategy of Kanban policy and its implementation will be valuable and reduce the instances of shortages.

Among the problems mention in this section, Raykar’s thesis [11] looks at the tradeoff between WIP and raw material inventory and more accurate supply chain performance indicator which is
mentioned in section 3.4.3. Daneshmand's thesis [9] addresses the problem of kitting described in sections 3.1.2 and 3.1.4.

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

3.1 Unnecessary Non-Value-Added operations

Non-value added (NVA) operations are those which are done by the operators but 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 which 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 are – 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, which together require more than 80 hours of labor. 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 sub-steps, however if done in a wrong way, would require several hours of rework. This is considered as a non-value-added operation.

As mentioned before, even with the instructions, the operators can still do the operations in several ways. Some operators can do some of the same operations in a more efficient manner taking far less than stipulated labor hours. Hence, the other ways of doing the same operations are considered to contain unnecessary NVA activities.

### 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. 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 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 part organizing system and improved communication of material flow. Daneshmand’s thesis [9] details this problem.

### 3.1.3 Supplier Quality Issue

Except for the sub-assemblies that come from Supermarket area, all the parts needed on the assembly line are from third party manufacturers. The materials and parts that come from the suppliers are not always clean enough to be assembled. Most of the time, the unclean parts need to be taken apart and cleaned in order to avoid potential rework. Also, parts coming from the 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 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.

3.2 Inefficient information and material flow

The material needed for assembly on the mixed module line comes from three sources viz. the Supermarket area, external storage locations Buildings 80, 5 and 70, and the MOD storage area on the shop floor. As Figure 4 shows, the Flow Line uses three different communication systems – MRP, Z-pick and Z-pick List – to pull material from the three different sources.
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, which was 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 in close vicinity of 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 5 shows the 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. Thus, only the operators at the warehouse know the shortage condition, which always causes confusion for the flow line operators.

When the out of stock parts are made available to the warehouse, they are at times are delivered directly to the machine (path 2 showed in Figure 4) whereas other times they are delivered to a shortage rack (path 1 showed in Figure 4). 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.

3.2.2 Assembly and Testing Bay Material Flow

As mentioned in section 3.2.1, the assembly bay receives parts from the warehouse. At the time of reception, no information of shortage is provided. As a result, the operators need to go through all the bins before knowing that a part is missing. This is a huge waste of labor. Besides, 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 Figure 4). 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.

During the test, failed parts 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 Figure 4). At the highest level of urgency, the test technician will get 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 Figure 4).

In either case, the test technician sends a request for parts through the SAP system (path (3) showed in Figure 4). 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 delay 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 get tested again 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 unavoidable 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 super market 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

<table>
<thead>
<tr>
<th>Module</th>
<th>Reason 1</th>
<th>Reason 2</th>
<th>Reason 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>90° Module</td>
<td>Supplier: 39%</td>
<td>In-house manufacturing: 25%</td>
<td>Material Handling: 9%</td>
</tr>
<tr>
<td>Terminal Module</td>
<td>Supplier: 47%</td>
<td>In-house manufacturing: 23%</td>
<td>Miscellaneous: 7%</td>
</tr>
</tbody>
</table>

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. Every time the operator working in test bay need a part, he or she has to go through this complex process. 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 a strategic and operational level. The main problems observed were as follows -

1. Material shortages
2. Unnecessary WIP
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. However there are some shortages which hold back production because those parts or subassemblies which are out of stock are crucial in the build process.

Several reasons are identified for material shortages. The biggest contributor of the shortages is unavailability of parts from the suppliers on time. While the uncertain demand and changing customer orders are a big driver of shortages, Varian also resists holding inventory to offset this variability. The materials managing function 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

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

The way the materials function measures shortages is different. The metric used by them is called ‘shorts at laydown’ which measures the number of parts which are less than 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 5 shows this.

![Builds vs. Shortages](image)

**Figure 6: 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 figure 7.

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
Figure 7: 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. The observation on 6/9/2011 also shows a tool laid down in an area outside the 90° module bays, but being idle.

Many times a tool can sit idly and not be worked upon because it is not a priority sales order. Another reason why a tool may be idle is shortages. While not all shortages stop the build process altogether, the build can no longer be continued if there are too many shortages or if a critical item runs short. This is observed for the machine number 137899. This machine faced part shortages throughout, and at times the shortage was critical and the machine had to be kept idle waiting for the parts to arrive.
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. This disrupts the build process and often causes rework to make the demanded changes to the tool. The chance of this occurring is greater with a higher WIP when there are more tools being worked upon. One of the principles of lean manufacturing is to have the least WIP inventory possible. The reason for this is that higher WIP tends to hide problems which would otherwise have been seen. Thus the WIP offers a sense of comfort, and prevents the root causes of operational problems being observed or acted upon. Also, if a quality issue is discovered down the line, there is a high probability that the other tools in WIP inventory might also have the same defect, thereby causing a lot of waste to correct the problem. Finally, having a high WIP with more tools spending longer time on the shop floor reduces the turnaround time and returns on inventory.

3.4.3 Inaccurate supply chain performance indicators

Varian’s Logistics department is responsible for sustaining 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

3.4.3.1 Shorts at laydown

The Logistics department measures the number of shortages using a software package called RapidResponse which sources data from Varian’s SAP Enterprise Resource Planning system. The software finds out which parts are needed on the scheduled build date and detects which parts are unavailable. This data is recorded for all tools in a month and a monthly average of
number of out of stock parts is calculated. This is the shorts at laydown metric used by the company.

There are 4 problems associated with how this shortage is measured, which diminish the accuracy of the data. They are –

1. Changes to scheduled laydown date
2. Actual need date for a part
3. Exclusion of Kanban parts from the shorts at laydown metric
4. Availability gap between SAP and Reality

The scheduled laydown date is subject to changes. It may get shifted earlier or the laydown might get postponed owing to customer requirements. Thus, counting which parts are short on a particular scheduled date does not accurately reflect if there is actual demand on the shop floor for those parts.

Secondly, not all parts are needed on the day of the laydown itself. The build process usually requires 4 to 5 days depending on the machine configuration, and not all parts are needed on the 1st day or the day of the laydown. In fact, sub-assemblies needed for the tool, which are assembled in the supermarket area need parts up to 5 days before the tool is laid down. Thus, the parts needed for this sub-assembly would be needed a few days before the laydown. Likewise, some parts or assemblies might be needed well beyond the laydown date, and are not required until then. Thus the short at laydown metric does not measure if the shortage is ‘real’, that is for an actual demand or shop order.

Thirdly, when calculating the shorts at laydown metric, Vendor Managed Inventory (VMI) parts and Kanban parts are removed from the list of shortages. The VMI parts are removed because these are mainly low value hardware items like nuts and bolts, which are situated at several bins on the shop floor, and thus do not really affect the build. The Kanban parts are removed because the shortages are measured on scheduled laydown date, and not the actual laydown date whereas the Kanban parts are delivered as per actual laydown date. This exclusion seems reasonable.
However, our analysis of historic shortage data, which is discussed in section 4.1.3.2 and summarized in section 6.1.1, reveals that 34.89% of the top 15% shortage contributor parts are in fact Kanban items. Thus, while the exclusion of Kanban parts from the shorts at laydown metric is logically consistent, the metric is inherently incorrect, and gives an inaccurate picture of the shortages.

Finally, there is a gap between the real availability of a part and the availability inside SAP system as a result of their procedure of receiving. Take Building 80 receiving for example, as shown in Figure 8, there is a worst case 14 hours gap between the part's actual availability in SAP and its real availability. In such case, there could be a shortage when SAP says the part is available.

![Figure 8: Gap between SAP and reality](image)

### 3.4.3.2 Supplier on time to need

This metric is used by Varian to measure what percent of time a supplier delivers parts early or on time for a machine's scheduled laydown date. Varian’s suppliers access a web portal which shares the MRP data of which parts are needed, in what quantity and by which date. The supplier can also see how many parts already exist in inventory at Varian’s warehouses and can thus plan its delivery accordingly. Varian measures what percent of time the supplier delivers material when there in actual requirement for it. If a delivery is received 0-5 days before the need date, it is considered to be on-time. If the delivery is received more than 6 days before need, it is
considered to be early. And if the delivery is 1 or more than 1 day after need date, it is considered late. The metric measures the percentage of deliveries which are early or on-time, averaged across all suppliers.

As in section 3.4.3.1 on shorts at laydown, the scheduled laydown date is subject to change, and is not an accurate measure of the exact date, whether earlier or later, that a part is required. Therefore, the shortage measured by this metric may not be ‘real’ i.e. there might not be an actual shop order for which the part is needed at that time. Also, the metric measures whether the delivery is on time, but not the individual parts. If two or more parts needed for different build orders in a delivery are late, it is still counted as 1 instance of late delivery. This does not reflect the shortage situation on the shop floor, where the shortage is perceived for every build order. Likewise, if several parts of the same type arrive under the PO, and only 1 of them is late against an order, the system still considers all of the parts as being late.

3.4.4 Common Shortage Parts and Kanban Policy

As illustrated in 3.4.3.1, the metrics of material shortage now is not accurate. Thus, an SAP transaction which recorded all the fulfillments of shortages when materials were received is used to evaluate shortage (This method will be discussed in further detail in section 5). An interesting result came out of the shortage history data of past years is that a huge amount of shortage instances are actually caused by a minor amount of parts. As showed in Table 5, according the shortage data of the past 2 years, 1% of the parts actually caused about 15% of the shortage instance. These are referred to Top Rank Parts later.

<table>
<thead>
<tr>
<th>Table 5: Common parts in shortage in the past 2 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>No. of parts</td>
</tr>
<tr>
<td>Count of instances of shortage</td>
</tr>
<tr>
<td>% of total</td>
</tr>
<tr>
<td>No. of orders</td>
</tr>
<tr>
<td>No. of shortages per order</td>
</tr>
<tr>
<td>This % of parts cause</td>
</tr>
<tr>
<td>This % of shortages</td>
</tr>
</tbody>
</table>
A large amount of shortage instances are actually caused by a small amount of parts. An improvement of the shortage situation of those parts will have a larger impact on the overall shortage situation. Of all the parts that are purchased by VSEA, there are mainly four kinds of inventory policies:

1. Kanban Policy
Most of the parts that are of high value are under Kanban Policy. There are two bins at stock for Kanban parts. For majority of the Kanban parts, each bin contains one lot sizes of inventory. At the beginning, parts are picked from the first bin. When the first bin is empty, a withdraw Kanban is issued to supplier to order a bin of parts. Meanwhile, the second bin becomes the first bin and parts are consumed from it. The lead time of most parts from supplier is about 5 days. The lot size are reviewed and adjusted every 3 months.

2. Consignment Policy and Vendor Managed Inventory Policy
Parts of relatively small value are under the policy of Consignment or VMI. For both policies, a certain amount of parts are stored at the Varian side, but Varian doesn't pay for the inventory until the parts are actually consumed. Suppliers have material handlers at Varian site who are in charge of checking and refilling the inventory to make sure that parts are never short.

3. Fix Lot Size Policy
The Fix lot size policy order parts for a fixed time period of consumption according to MRP's forecast of a specific part. The lot size of those parts are reviewed and adjusted quarterly.

Since inventory policies of lots of different parts have been changed in the past year, it is reasonable to find out the policy which caused the most of the shortage instances within past year. Shortage history data is shown in table 6, the data reflect the same pattern as shown before, which is 1% of the parts caused 15% of the shortage instances. A further discovery that the parts under Kanban policy caused the most shortage instances compared to other policies. The investigation and improvement Kanban policy at Varian will be the focus of this thesis.
Table 6: Shortage situation of the past year

<table>
<thead>
<tr>
<th>Time Range</th>
<th>2010.7.1- 2011.6.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total No. of parts</td>
<td>5186</td>
</tr>
<tr>
<td>Total Count of instances of shortage</td>
<td>15333</td>
</tr>
<tr>
<td>No. of parts</td>
<td>72</td>
</tr>
<tr>
<td>Caused Count of instances of shortage</td>
<td>2225</td>
</tr>
<tr>
<td>This % of parts cause</td>
<td>1.4%</td>
</tr>
<tr>
<td>This % of shortages</td>
<td>14.5%</td>
</tr>
</tbody>
</table>

4. Review of Literature

4.1 Lean Manufacturing

This section is meant to give 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 was 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.

1- **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 observations to map a representative VSM. Detailed observations and drawing spaghetti charts were the key for our team to be able to map the process.

2- **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.

3- **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 states 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 considered 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].

Methods of measuring service levels are commonly found in most books on supply chain planning strategies. Simchi-Levi et.al [10] discuss Type 1 and Type 2 service levels and give examples to demonstrate their use.
4.2 Inventory Policies

In order to initiate the investigation and to improve the Kanban policy, a review of literatures about classical pull inventory polices is considered necessary and helpful. The lecture material from MIT course 15.762, supply chain planning, discusses 2 pull inventory policies for stochastic demand, the Fixed Quantity Re-Order Point policy and Base Stock policy.

4.2.1 Q-R Inventory Policy

The Q-R inventory policy have a fixed ordering quantity \( Q \) and a re-order point \( R \). Whenever the inventory level drops below the re-order point \( R \), an order of fixed quantity of \( Q \) is released to refill the inventory level. Basically, the Q-R policy is a pull system policy, wherein re-ordering is pulled by consumption. Basic equations of the Q-R model are shown below:

The re-order point \( R \):

\[
R = \mu L + z \sigma \sqrt{L} \tag{1}
\]

\( \mu \) is the consuming rate, \( \sigma \) is the standard deviation of the consuming rate, \( z \) is the safety factory, and \( L \) is the lead time of an ordering quantity \( Q \).

Average Inventory level under this policy

\[
E[I] \approx \frac{E[I^-]+E[I^+]}{2} = \frac{Q}{2} + Z \sigma \sqrt{L} \tag{2}
\]

\( Q \) is the fixed ordering quantity.

4.2.2 Base Stock Policy

The concept of the base stock policy is to review the stock periodically in order to bring the inventory level back to a predetermined base stock level. The reviewing period and the base stock level are all fixed. This policy is another pull system policy. This policy is not suitable for manufacturing system where the demand fluctuate severely since the review period is fixed. At a big ramp up stage, the system could run out of stock because of the relatively long review period and low base stock level due to a big shift of demand rate. Important equations for the base stock model are shown below:
The base stock level:

\[ B = \mu(r + L) + z\sigma\sqrt{(r + L)} \]  

(3)

The average inventory level:

\[ E[I] \approx \frac{E[I^-]+E[I^+]}{2} = \frac{\mu r}{2} + z\sigma\sqrt{(r + L)} \]  

(4)

\( \mu \) is the consuming rate, \( \sigma \) is the standard deviation of the consuming rate, \( z \) is the safety factory, \( L \) is the lead time of an order and \( r \) is the fixed reviewing period.

### 4.2.3 Service level

Service level is considered as a crucial measurement of the supply chain. It measures the supply chain system's ability to satisfy the demand. The 2 major kinds of service are as:

Type I: Probability of stock out when there is a replenishment.

Type II (fill rate): Percentage of demand met from stock.

### 4.3 Kanban Policy

The Kanban policy was first utilized by Toyota Production System to achieve their goal of Just In Time (JIT) Inventory replenishment. Inventories under Kanban policy are usually store in bins attached with a Kanban (i.e. a card or tag) which has information of part name, quantity, production time, deliver time and supplier. When the parts in the bin get consumed, the Kanban is detached and sent back to the supplier as an order of the same quantity. The number of Kanban is a constant number so as to control the maximum inventory level. When the inventory reaches this maximum level and no parts get consumed, no Kanban is detached and sent as an order. The orders of this policy are pulled by actual demand instead of production scheduling. Compared to the production scheduling policy, the Kanban policy orders according to real consumption which eliminates the forecast inaccuracy. [15]

Two important parameter of Kanban Policy are the lot size and number of Kanban. Lot size is the ordering quantity of each Kanban sent to the supplier. The disadvantage of a small lot size is
that the supplier will have a higher changeover cost and lower throughput rate compared to large lot size. From the perspective of downstream manufacturing process, a small lost size is preferable since it give the downstream process more flexibility and less inventory cost. David Ian Moreria [16] discusses an EOQ model of the lot size which considers both the cost of the supplier and the inventory cost at the downstream process side. Important equations of the model are listed below:

Total cost C:

\[ C = IQ + \frac{S}{Q} \]  

(5)

I is unit inventory cost and S is setup cost. From that model, we can see that optimized lot size is:

\[ Q = \sqrt{\frac{S}{I}} \]  

(6)

Another important parameter that controls the maximum inventory level of the Kanban Policy is the total number of Kanbans. Since the major aim of using Kanban system is to reduce on-hand inventory [17], the number of Kanbans should be minimized as long as the inventory can satisfy the demand. A commonly used equation of calculating the number of Kanban K is:

\[ K = \frac{\mu L (1+SF)}{Q} \]  

(7)

\( \mu \) is the demand rate, L is lead time, SF is safety factor for safety stock and Q is container capacity.
5. Methodology

This section focuses on the methodologies used in finding the problem, the root cause of the problem the possible solution of the problem, including preliminary analysis, data collection, inventory models analysis.

5.1 Preliminary analysis

5.1.1 First person observations

The first step in the process of identifying areas for process improvements was 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 were –

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 2 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 takes 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. Daneshmand’s thesis [9] deals 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 here and in Raykar’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.
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 Current Kanban Policy

As stated in section 3.4.4, majority of the top 1% parts which caused 15% of the shortage instances are under Varian's Kanban inventory control policy. A detailed distribution of the policies of the 1% part is shown in table 7. Thus, it is valuable to investigate Varian's Kanban policy since theoretically a Kanban policy should effectively eliminate shortages instead of causing shortages.

Table 7: Distribution of 1% part in Inventory policy

<table>
<thead>
<tr>
<th>Count</th>
<th>Special Procurement</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>751</td>
<td>KC – Cell Kanban</td>
<td>33.75%</td>
</tr>
<tr>
<td>490</td>
<td>KI – MRP driven</td>
<td>22.02%</td>
</tr>
<tr>
<td>376</td>
<td>VO – Purchased part (Varian design)</td>
<td>16.90%</td>
</tr>
<tr>
<td>357</td>
<td>PO – Purchased part (OEM part)</td>
<td>16.04%</td>
</tr>
<tr>
<td>225</td>
<td>SO – Shop order</td>
<td>10.11%</td>
</tr>
<tr>
<td>26</td>
<td>KB – Floor Release Kanban</td>
<td>1.17%</td>
</tr>
<tr>
<td>2225</td>
<td>Grand Total</td>
<td></td>
</tr>
</tbody>
</table>
The investigation of current Kanban policy considered both the current lot sizing strategy and the policy's implementation quality. The Kanban policy at Varian is different from traditional Kanban policy. There are two bins of inventory for each part, and the two bins are all full at the beginning. The parts start being consumed from the first bin and the Kanban attached with the first bin stays with the bin until the first bin is empty. On the contrary, in traditional Kanban policy, the Kanban is detached and sent to the upstream process as an order when the parts start being consuming from a bin. The lot size of Kanban policy at Varian is 2 weeks' worth of demand and it is reviewed and adjusted every 3 months. The lot size is calculated based on forecast of the next 3 months of demand. The lead time of 90% of the parts under Kanban policy is 5 days. With this lot sizing strategy, 5 days of demand is supposed to be covered with 2 weeks' worth of demand. Nevertheless, the problem with the current lot sizing strategy does not take the variance of the demand into consideration. According to this specific Kanban policy at Varian, a Q-R model can be used to describe their current policy. In this Q-R model, the reorder point \( R \) equals the order quantity \( Q \). Here, \( \mu \) is the daily demand of the part and \( \sigma \) is the standard deviation of daily demand. The lead time \( L \) is 5 days and \( Q \) and \( R \) are 14\( \mu \). Written as equations:

\[
Q = R = 14\mu 
\]

\[
L = 5 
\]

\[
E[I] = \frac{E[I^-]+E[I^+]}{2} = \frac{9\mu+23\mu}{2} = 16\mu 
\]

5.2.1 Data Collection

In order to evaluate the strategy and implementation of current Kanban policy, historical data of shortages, purchase orders and demand is needed to be collected.

As stated in section 3.4.3, the current way of measuring the material shortage is not accurate. Thus, a more accurate way is used here to collect shortage data. As shown in figure 8, when receiving materials, a shortage ticket which records the quantity of the shortage and receiving date will be attached to the material if there are shortages of that material. After that, the materials are delivered to the shop floor with the shortage ticket. All the information on the shortage ticket is also recorded in the SAP system as it is issued. So, an evaluation of the
shortage data would be a good measurement of real shortage. A sample of shortage data is shown below in table 8.

**Table 8: Sample Shortage data**

<table>
<thead>
<tr>
<th>Material Number</th>
<th>Pstg date</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>E37XXXXX</td>
<td>XX/XX/20XX</td>
<td>-6</td>
</tr>
</tbody>
</table>

Besides, in order to find the causes of the shortages under Kanban Policy, the demand data and purchase data are also needed. The receiving date, quantity and order number of every purchase order (PO) are recorded under transactions in SAP. The receiving data of PO used here are recorded as the warehouse actually receiving the material. Thus, the quantity and receiving date of the PO recorded are valid and accurate in SAP. A sample PO data is shown in table 9.

**Table 9: Sample PO data**

<table>
<thead>
<tr>
<th>PO</th>
<th>Quantity</th>
<th>Receive Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>92XXXX Subtotal</td>
<td>18.000</td>
<td>XX/XX/20XX</td>
</tr>
</tbody>
</table>

The current Kanban policy calculates the lot size of the Kanban by looking at the forecast data. This way of calculation of lot size ignores the consumption caused by failure of parts during material handling, assembly and testing. In such a case, the real historical demand data might be valuable for proposing new lot sizing policy. The actual monthly demand data can also be obtained using SAP system, which includes the consumption by all the major causes. A sample of the demand data is shown in Table 10.

**Table 10: Sample demand data**

<table>
<thead>
<tr>
<th></th>
<th>Jun-11</th>
<th>May-11</th>
<th>Apr-11</th>
<th>Mar-11</th>
<th>Feb-11</th>
<th>Jan-11</th>
<th>Dec-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1132XXXX</td>
<td>1X</td>
<td>1X</td>
<td>1X</td>
<td>2X</td>
<td>1X</td>
<td>2X</td>
<td>1X</td>
</tr>
</tbody>
</table>

5.3 **Analysis of current Kanban System**

In order to improve the old Kanban system and reduce the shortage instances caused by the parts that are under Kanban policy, a root cause investigation was done. Three main causes were
found through the investigation. Details about the three causes and the methodologies used to identify them are illustrated in this section.

5.3.1 Type I service rate and general analysis

The definition of type I service rate is the probability of stock out during a replenishment period. In order to calculate the type I service rate, the receiving data and the PO data were compared side by side. For the same part, if one or several shortages were fulfilled at the same date of a receiving, it means the part was out of stock during the replenishment period. And type I service rate is calculated using the following equation:

\[
Type I = \frac{\text{The number of stock out during replenish period}}{\text{The number of purchase order}}
\]

The service rate of all the Kanban parts that inside the 1% of the Top Rank Parts are calculated and shown at the section 5.4.5

5.3.2 Supplier's failure to deliver on time

When investigating the receiving data, it is found that the same purchase order sometimes arrived at several different date. The reason of this is the supplier's inability of deliver the full quantity of the purchase order at order due date. In such a case, the suppliers would deliver whatever amount they have on the due date and deliver the rest of the order at a later time. The same order might be delivered at full quantity at the second time of delivery, but sometimes the same order was delivered at several different times to be completed. If the receiving date of a purchase order other than the first receiving date was found to be the same date as that of a shortage fulfillment, it is obvious that the shortage was caused by failure to deliver the full order on time.

The percent of orders that were failed to be delivered in full order is calculated and shown in section 5.4.5

5.3.3 Higher demand rate

From the analysis of shortage and PO data, the second reason found to be the cause of shortages is a demand rate higher than expected. According to section 5.3, since the current Kanban policy
does not consider the standard deviation of the demand, the probability that the demand is higher than reorder point (type I service rate) is not considered. As a result, there is no control over the type I service rate under current policy. When analyzing the data, the lead time is assumed to be 5 days for all the orders. Thus, if the gap between the receiving dates of two purchase orders is less than 5 days (Lead time), it is deduced that the gap between the order dates of the two purchase orders is also less than 5 days, which means the second order was made before the first order was fulfilled. In other words, the demand rate during lead time is higher than the re-order point. The percent occurrence of this situation is calculated and shown in section 5.4.5

5.3.4 Implementation

In addition to the two reasons mentioned above, poor-implementation of the Kanban policy is also found to be a cause of shortages of Kanban parts. Firstly, according to the receiving data, the order quantity of the POs within 3 month is not all the same. Some orders have less quantity than orders which caused shortage in the following replenish period. Secondly, sometimes a PO is not sent to the supplier when the inventory level is lower than reorder point.

5.3.5 Summary

As stated above, failure to fulfill order on time, demand rate higher than projected and poor implementation of Kanban policy are considered the three main causes of the shortages of the Top Rank Parts that are under Kanban policy. Table 11 and Figure 9 below shows the type I service rate, percentage of order that failed to be delivered on time and the percentage of the instances that the demand rate during lead time is higher than the re-order point of the Top Rank Parts that are under Kanban policy.

Table 11: Summary of causes of shortages

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Type I Service Rate</th>
<th>Percentage of failure to deliver</th>
<th>Percentage of higher demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>E11325690</td>
<td>0.0%</td>
<td>64.7%</td>
<td>5.9%</td>
</tr>
<tr>
<td>E33000206</td>
<td>54.2%</td>
<td>6.3%</td>
<td>35.4%</td>
</tr>
<tr>
<td>E11322512</td>
<td>40.0%</td>
<td>38.5%</td>
<td>41.5%</td>
</tr>
<tr>
<td>E20000470</td>
<td>52.6%</td>
<td>28.1%</td>
<td>61.4%</td>
</tr>
<tr>
<td>E16082434</td>
<td>48.0%</td>
<td>12.0%</td>
<td>28.0%</td>
</tr>
<tr>
<td>E19294231</td>
<td>65.7%</td>
<td>25.7%</td>
<td>28.6%</td>
</tr>
<tr>
<td>E11122580</td>
<td>55.6%</td>
<td>14.8%</td>
<td>14.8%</td>
</tr>
<tr>
<td>E37000209</td>
<td>65.2%</td>
<td>0.0%</td>
<td>8.7%</td>
</tr>
<tr>
<td>Code</td>
<td>Service Rate</td>
<td>Failure to Deliver</td>
<td>Consumption</td>
</tr>
<tr>
<td>------------</td>
<td>--------------</td>
<td>--------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>E32000045</td>
<td>52.0%</td>
<td>12.0%</td>
<td>16.0%</td>
</tr>
<tr>
<td>E23000371</td>
<td>75.0%</td>
<td>70.8%</td>
<td>16.7%</td>
</tr>
<tr>
<td>E11116740</td>
<td>64.7%</td>
<td>32.4%</td>
<td>8.8%</td>
</tr>
<tr>
<td>E33000207</td>
<td>70.2%</td>
<td>3.5%</td>
<td>47.4%</td>
</tr>
<tr>
<td>E19008510</td>
<td>44.4%</td>
<td>33.3%</td>
<td>11.1%</td>
</tr>
<tr>
<td>E19013484</td>
<td>84.6%</td>
<td>36.9%</td>
<td>21.5%</td>
</tr>
<tr>
<td>E11366160</td>
<td>58.3%</td>
<td>66.7%</td>
<td>16.7%</td>
</tr>
<tr>
<td>E32000150</td>
<td>65.2%</td>
<td>4.3%</td>
<td>0.0%</td>
</tr>
<tr>
<td>E17396270</td>
<td>66.7%</td>
<td>0.0%</td>
<td>8.3%</td>
</tr>
<tr>
<td>E11365920</td>
<td>84.1%</td>
<td>34.1%</td>
<td>25.0%</td>
</tr>
<tr>
<td>E11365890</td>
<td>72.4%</td>
<td>51.7%</td>
<td>27.6%</td>
</tr>
<tr>
<td>E15004180</td>
<td>84.6%</td>
<td>23.1%</td>
<td>11.5%</td>
</tr>
<tr>
<td>E11312111</td>
<td>93.2%</td>
<td>11.4%</td>
<td>6.8%</td>
</tr>
<tr>
<td>E11292270</td>
<td>69.2%</td>
<td>0.0%</td>
<td>10.3%</td>
</tr>
</tbody>
</table>

Figure 9: Summary of causes of Shortages
5.4 New policy proposal and simulation

As mentioned in section 5.2, the current Kanban lot sizing policy is based on forecast of demand rather than real demand. Besides, the old lot sizes model does not take the variance of the demand into consideration. A series of new policies are proposed in this section and they are compared with the old Kanban policy in terms of Type I service rate and inventory cost.

5.4.1 New policies

According to section 5.3, the only available actual demand data are the monthly demand data. Thus, monthly demand data were used here to develop a new model and calculate the service rate of the data. Traditional Q-R model is used here to calculate the reorder point R. The current lot size review period of the Kanban policy is 3 months and it is not changed for the first policy proposed. In this new model, the past three months demand data are used to calculate the lot size of the next three months. A projected service rate of 95% is used here:

\[ Q = R = \mu_M + z_{0.95} \cdot \sigma_M \]  

(12)

Q and R is the lot size, \( \mu_M \) is the average of the past three months demand, \( \sigma_M \) is the standard deviation of the past three months demand.

Two other policies are generated using the same method with two months lot size review period and one month lot size review period respectively.

5.4.2 Type I service rate comparison

In order to evaluate the performance of the new policies, the type I service rate are calculated. Since the order made at the beginning of the \( n^{th} \) month is going to arrive at the end of \( n^{th} \) month and is supposed to cover the demand starting the \( n + 1^{th} \) month, for the three months review period policy, the type I service rates are calculated by getting the probability that \( n + 1^{th} \), \( n + 2^{th} \) and \( n + 3^{th} \) months' demands that are covered by the lot size generated from the demand data of \( n - 1^{th} \), \( n - 2^{th} \) and \( n - 3^{th} \) month. Under the same logic, for the two months review period policy, the type I service rate is calculated by get the probability that \( n + 1^{th} \) and
\( n + 2^{th} \) months' demands that are cover by the lot size generated from the demand data of 
\( n - 1^{th}, n - 2^{th} \) and \( n - 3^{th} \) month. For the one month review period policy, the type I service rate are calculated by the probability that \( n + 1^{th} \) month's demands that are cover by the lot size generated from the demand data of \( n - 1^{th}, n - 2^{th} \) and \( n - 3^{th} \) month. The service rate of the 3 new policies and the current policy are compared and shown in table 12 and figure 10.

**Table 12: Comparison of new policies and current policy**

<table>
<thead>
<tr>
<th>Part</th>
<th>Current</th>
<th>3 months Review</th>
<th>2 months review</th>
<th>1 month review</th>
</tr>
</thead>
<tbody>
<tr>
<td>E11325690</td>
<td>0.00%</td>
<td>66.67%</td>
<td>80.00%</td>
<td>77.78%</td>
</tr>
<tr>
<td>E33000206</td>
<td>54.17%</td>
<td>77.78%</td>
<td>80.00%</td>
<td>77.78%</td>
</tr>
<tr>
<td>E11322512</td>
<td>40.00%</td>
<td>77.78%</td>
<td>70.00%</td>
<td>77.78%</td>
</tr>
<tr>
<td>E20000470</td>
<td>52.63%</td>
<td>88.89%</td>
<td>80.00%</td>
<td>88.89%</td>
</tr>
<tr>
<td>E16082434</td>
<td>48.00%</td>
<td>100.00%</td>
<td>90.00%</td>
<td>88.89%</td>
</tr>
<tr>
<td>E19294231</td>
<td>65.71%</td>
<td>77.78%</td>
<td>60.00%</td>
<td>77.78%</td>
</tr>
<tr>
<td>E11122580</td>
<td>55.56%</td>
<td>77.78%</td>
<td>70.00%</td>
<td>88.89%</td>
</tr>
<tr>
<td>E37000209</td>
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<td>66.67%</td>
<td>80.00%</td>
<td>77.78%</td>
</tr>
<tr>
<td>E32000045</td>
<td>52.00%</td>
<td>88.89%</td>
<td>90.00%</td>
<td>88.89%</td>
</tr>
<tr>
<td>E23000371</td>
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<td>77.78%</td>
<td>80.00%</td>
<td>66.67%</td>
</tr>
<tr>
<td>E11116740</td>
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<td>90.00%</td>
<td>88.89%</td>
</tr>
<tr>
<td>E33000207</td>
<td>70.18%</td>
<td>88.89%</td>
<td>90.00%</td>
<td>88.89%</td>
</tr>
<tr>
<td>E19008510</td>
<td>44.44%</td>
<td>77.78%</td>
<td>80.00%</td>
<td>77.78%</td>
</tr>
<tr>
<td>E19013484</td>
<td>84.62%</td>
<td>88.89%</td>
<td>90.00%</td>
<td>88.89%</td>
</tr>
<tr>
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<td>88.89%</td>
<td>90.00%</td>
<td>88.89%</td>
</tr>
<tr>
<td>E32000150</td>
<td>65.22%</td>
<td>77.78%</td>
<td>80.00%</td>
<td>88.89%</td>
</tr>
<tr>
<td>E17396270</td>
<td>66.67%</td>
<td>77.78%</td>
<td>80.00%</td>
<td>77.78%</td>
</tr>
<tr>
<td>E11365920</td>
<td>84.09%</td>
<td>88.89%</td>
<td>90.00%</td>
<td>88.89%</td>
</tr>
<tr>
<td>E11365890</td>
<td>72.41%</td>
<td>88.89%</td>
<td>90.00%</td>
<td>88.89%</td>
</tr>
<tr>
<td>E15004180</td>
<td>84.62%</td>
<td>66.67%</td>
<td>80.00%</td>
<td>77.78%</td>
</tr>
<tr>
<td>E11312111</td>
<td>93.18%</td>
<td>77.78%</td>
<td>90.00%</td>
<td>77.78%</td>
</tr>
<tr>
<td>E11292270</td>
<td>69.23%</td>
<td>77.78%</td>
<td>80.00%</td>
<td>77.78%</td>
</tr>
</tbody>
</table>

| Total        | 62.09%  | 81.31%         | 82.27%          | 82.83%        |
5.4.3 Inventory cost comparison

Apart from the service rate, inventory cost is also another important factor to judge the performance of an inventory policy. The average inventory level of the current policy and three new policy are calculated and compared in this section. As illustrated in section 5.2, the average inventory level of the current policy is:

\[
E[I] = \frac{E[I^-] + E[I^+]}{2} = 16\mu = \frac{16}{15}Q
\]  

(13)
μ is the daily demand and Q is the current lot size. The yearly average inventory level is the average of all the inventory level of all the lot size weighted by the length of their usage across the year.

For the new policies, since only monthly demand data is available, the lot size of a lead time of 5 days is deducted using the following way. It is assumed that the average daily demand is μ and the standard deviation of daily demand is σ. It is also assumed that each day's demand is independent. Thus:

\[ \mu_M = 30\mu, \quad \mu_L = 5\mu = \frac{\mu_M}{6} \]  
\[ \sigma_M = \sqrt{30}\sigma, \quad \sigma_L = \sqrt{5}\sigma = \frac{\sigma_M}{\sqrt{6}} \]  
\[ Q' = \mu_L + z_{0.95} \times \sigma_L \]  
\[ E[I'] = \frac{Q'}{2} + z_{0.95} \times \sigma_L \]

μ_M is the mean of monthly demand data, σ_M is the standard deviation of monthly demand data, and μ_L is the demand during the lead time of 5 days and σ_L is the standard deviation of the demand during lead time of 5 days. Q' is the new lot size and E[I'] is the average inventory level under the new lot sizing policy.

The inventory level of the new inventory policies are calculated using the formulas shown above weighted by the time period that the lot size are used. The inventory level of the new policies are shown in table 13 below and are compared with the current policy. Concerning the issue of confidentiality of the data involved, the inventory of the new policies are shown in terms of the percentage of the current inventory level.

**Table 13: Inventory level of new policies**

<table>
<thead>
<tr>
<th>Part</th>
<th>3 months review</th>
<th>2 month review</th>
<th>1 month review</th>
</tr>
</thead>
<tbody>
<tr>
<td>E11325690</td>
<td>54.90%</td>
<td>59.86%</td>
<td>64.94%</td>
</tr>
<tr>
<td>E33000206</td>
<td>64.17%</td>
<td>57.86%</td>
<td>57.34%</td>
</tr>
<tr>
<td>E11322512</td>
<td>91.71%</td>
<td>87.92%</td>
<td>87.36%</td>
</tr>
<tr>
<td>E20000470</td>
<td>116.49%</td>
<td>129.89%</td>
<td>123.43%</td>
</tr>
<tr>
<td>Code</td>
<td>First Value</td>
<td>Second Value</td>
<td>Third Value</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------</td>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>E16082434</td>
<td>127.76%</td>
<td>113.06%</td>
<td>123.17%</td>
</tr>
<tr>
<td>E19294231</td>
<td>97.17%</td>
<td>87.88%</td>
<td>84.48%</td>
</tr>
<tr>
<td>E11122580</td>
<td>100.96%</td>
<td>82.32%</td>
<td>94.43%</td>
</tr>
<tr>
<td>E37000209</td>
<td>60.83%</td>
<td>62.11%</td>
<td>66.41%</td>
</tr>
<tr>
<td>E32000045</td>
<td>49.76%</td>
<td>54.40%</td>
<td>52.86%</td>
</tr>
<tr>
<td>E23000371</td>
<td>32.98%</td>
<td>28.32%</td>
<td>27.39%</td>
</tr>
<tr>
<td>E11116740</td>
<td>77.20%</td>
<td>67.76%</td>
<td>62.35%</td>
</tr>
<tr>
<td>E33000207</td>
<td>80.49%</td>
<td>70.43%</td>
<td>73.97%</td>
</tr>
<tr>
<td>E19008510</td>
<td>63.42%</td>
<td>65.53%</td>
<td>64.26%</td>
</tr>
<tr>
<td>E19013484</td>
<td>109.89%</td>
<td>104.04%</td>
<td>104.86%</td>
</tr>
<tr>
<td>E11366160</td>
<td>52.93%</td>
<td>46.56%</td>
<td>49.71%</td>
</tr>
<tr>
<td>E32000150</td>
<td>39.45%</td>
<td>39.95%</td>
<td>42.65%</td>
</tr>
<tr>
<td>E17396270</td>
<td>59.92%</td>
<td>57.58%</td>
<td>61.68%</td>
</tr>
<tr>
<td>E11365920</td>
<td>81.06%</td>
<td>69.99%</td>
<td>71.66%</td>
</tr>
<tr>
<td>E11365890</td>
<td>121.86%</td>
<td>113.24%</td>
<td>122.32%</td>
</tr>
<tr>
<td>E15004180</td>
<td>53.79%</td>
<td>52.28%</td>
<td>62.18%</td>
</tr>
<tr>
<td>E11312111</td>
<td>70.39%</td>
<td>64.81%</td>
<td>71.86%</td>
</tr>
<tr>
<td>E11292270</td>
<td>267.61%</td>
<td>315.85%</td>
<td>322.84%</td>
</tr>
</tbody>
</table>
6. Results and Future works

6.1 Results

As it is shown in table 12 in section 5, the proposed new inventory policy in an ideal case could actually provide higher Type I service rate than current Kanban policy. Additionally, it is also shown that shorter lot size review period provides higher Type I service rate. Besides, according to the result shown in table 13, for majority of the parts, the inventory level of these new policies are lower than the current policy, whereas for minority of the parts, the inventory level of using these new policies are higher than current policy. Thus, in general, the inventory cost of these new policies are lower than current policy.

6.2 Recommendations

6.2.1 Usage of demand data

According to the analysis done in section 5, the demand data is proved to be useful and more accurate as predictor of future demand. As mentioned, the forecast doesn't take into account the consumption caused by parts failure which is a noticeable portion of the total consumption. From the result, the lot size determined by the previous demand provide higher service level than current lot sizing algorithm. Thus, the use of the demand data at lot sizing is recommended here.

6.2.2 Shorter lot size review period

From the policies comparison in section 5, it is shown that shorter the lot size review period that the policy utilize, the higher the overall service rate the policy will perform. Theoretically, a shorter lot size review period will be more sensitive to the trend of the demand. Besides, the inventory level is not necessarily higher than current policy. In contrast, the inventory level of the most the parts are actually lower than the current policy. Noticeably, the service rates and average inventory levels calculated in section 5 are under the assumption that the supplier can deliver the full quantity of the purchase order on time and the Kanban policy is strictly
implemented. From the result, it is recommended that shorter review period should be utilized in order to achieve better service rate.

6.3 Future works

The analysis used in section 5 could be considered as an early stage analysis of which several aspects could still be improved and further validated. Firstly, the demand data used in section 5 is monthly demand which could only generate a rough analysis and simulation of the demand. Demand analysis of smaller time chunk are recommended to be done in future which might provide more solid validation and more accurate lot size. Secondly, the current analysis only considered the demand of the past three months for future lot size. Longer time period of demand history might be able to provide better prediction of future demand and the Exponentially Weighted Moving Average (EWMA) method might be introduced to the analysis and valuable to detect the trend of the demand. Those analysis are valuable to be taken and to be compared with the new policies mentioned in section 5. Finally, the implementation of Kanban policy need to be strict in future studies so that the data can reflect more the effect of the policy instance of noises.
7. References


