Abstract

This thesis tackles the Supermarket (SMKT) material shortage problem at Varian Semiconductor Equipment and Associates (Varian), in a bid to improve the SMKTs On-Time Delivery. The SMKT is a sub-assembly area that creates intermediate assemblies in a multi-stage ion implanter production process. However, many sub-assemblies made in the SMKT are delivered late. When juxtaposed with Varians external suppliers, which have On-Time Delivery records of over 90%, the SMKTs average of 61% pales in comparison. SMKTs poor On-Time Delivery has been tied to production delays and rework downstream on the Flowline. From a large amount of data collected on-site, a SMKT material shortage problem is found to be the root cause of its unsatisfactory On-Time Delivery. Random supply shocks have resulted in material shortages, which in turn lead to late deliveries. The majority (i.e. 64%) of shortages is the result of having two inventory storage locations: SMKT and Varians Warehouse. To resolve the material shortage problem, Varian can consider consolidating its SMKT inventory to one single storage location, such as the Warehouse. This is expected to save Varian $467,488 per annum in labor hours and rent, free up 3,000 ft2 of production floor space for capacity expansion, and decrease cycle time of an oft-late sub-assembly called the Profiler by 11%. This is on top of eliminating the aforementioned 64% of shortages. The consolidation strategy will put Varian in a productive and competitive position to capitalize on the fast-growing semiconductor industry in the years ahead.
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It is time for us to take on the world!
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1. Introduction

1.1. The Semiconductor Capital Equipment Industry

1.1.1. Overview

The semiconductor capital equipment industry displays characteristics of an oligopolistic market structure. There is a small number of large firms, which include Applied Materials, Tokyo Electron Limited, and KLA-Tencor Corporation [1]. The production floors, clean rooms and even Warehouses all require substantial capital investment. This creates high barriers to entry for new entrants.

1.1.2. Future Outlook

The industry outlook is very positive. Samsung, currently the world’s second biggest chip manufacturer, announced in July 2017 that they will be investing $18 billion to expand its South Korean manufacturing capabilities [2]. NVIDIA, the leader in graphics processing, also increased their Research and Development Expense from 27% to 31% in 2017[3]. This push for expansion has been driven by the strong performance of the smartphone industry, as well as the rising demand needs by emerging IT trends, such as big data, self-driving cars, and the Internet of Things.

1.2. Company Background

1.2.1. Overview

Varian Semiconductor Equipment Associates is a market leader in ion implantation equipment manufacturing. Founded in 1971 in Peabody, Massachusetts under the name Extrion Corporation, Varian has evolved over the years. It moved to Gloucester, Massachusetts after being acquired by Varian Associates in 1975. As the industry consolidates further, Varian was acquired by Applied Materials in 2011. As of 2007, Varian owns 65% of the ion implanter market share, with its closest competitors Axcelis Technologies, Inc holding 12%, and Sumitomo Eaton Nova Corporation 10% [1]. Varian’s customers include the likes of Intel, Samsung, and Taiwan Semiconductor Manufacturing Company.
1.2.2. Ion Implanter Market

The ion implanter equipment industry is a high volatile industry with distinct “five-year cycles” (see Figure 1-2). This is the result of a combination of technology and market forces, which include “shifts in dominant wafer sizes, introduction of new implanter machine types and IC devices, expansion into new global regions, and variations driven by general economic cycles” [4].
1.2.3. Product Line

Varian manufactures three main types of ion doping equipment: high current, medium current, and high energy. Among its most popular products are the VIISta Trident, a technologically advanced single-wafer high-current ion implanter, and the VIISta 900XP, a medium current version of the Trident (see Figure 1-3). Ion doping is a critical step in microchip manufacturing. The physics behind the process involves accelerating ions in an electric field onto a silicon wafer substrate, which will then be processed into transistors on integrated circuits to power our electronic devices.

![Diagram of ion doping equipment](image)

Figure 1-3: VIISta 900XP[4]

In total, there are approximately 40 different steps to microchip manufacturing (Figure 1-4). The steps can be categorized into deposition, removal, patterning, and modification of electrical properties. Ion implantation falls under the final step.

![Diagram of microchip manufacturing process]

Figure 1-4: Process of Microchip Manufacturing
1.3. Non-Technical Problem Description

As a result of the recent semiconductor boom, Varian is experiencing an extended period of high demand. With production rate ramping up, Varian has found it challenging to maintain a satisfactory On-Time Delivery standard out of its sub-assembly production floor, otherwise known as the Supermarket (SMKT). The SMKT is a non-dedicated production floor that manufactures sub-assemblies needed for the ion implanter (Tool) production line (Flowline). It is also an inventory area that stores parts needed for the SMKT sub-assemblies and the Flowline. Apart from going onto the Flowline, the sub-assemblies can also be used to replenish a sub-assembly safety stock area (Gold Squares), or be made for specific Customer Order. As of late, the SMKT has only been able to maintain an average On-Time Delivery of 61% (see Figure 1-5). An acceptable On-Time Delivery target is 90%, the On-Time Delivery criteria for most of Varian’s external suppliers. SMKT’s poor On-Time Delivery is tied to problems downstream on the Flowline. In face of rising demand, resolving the issue swiftly and decisively will help Varian secure a productive and competitive position in the semiconductor equipment market.

![SMKT Completed Kits](image)

Figure 1-5: SMKT On-Time Delivery Record
1.4. Thesis Organization

1.4.1. Thesis Project Execution

This project is carried out at Applied Materials (NASDAQ: AMAT) Varian Semiconductor as part of the degree requirement for the Master of Engineering in Advanced Manufacturing and Design program. The MIT team is made of four students: Ruolin Xu, Yadunund Vijay, Yuwen Zhang and Zongying Xu. The team worked part-time on Friday afternoons from January to May 2017, and full-time from May to August. The team was assigned the project to improve the On-Time Delivery of sub-assemblies from the SMKT. Through preliminary interview with managers and engineers, the MIT team identified two main approach to address the problem:

1. Prioritization
   There is no standard protocol in the shop order picking and assembly procedure. Pickers have the freedom to go through the pile of shop orders to find the one she wants to pick. Assemblers do not know which kit they should assemble when the production lead is absent.

2. Material shortage
   When a kit is picked to short, the kits have to stay in a designated area to wait for the parts. Material shortage prevents proper prioritization of build sequence.

1.4.2. Summary of Work

Based on these two approaches, the team divided the work and identified three paths to improve the On-Time Delivery of the SMKT:

1. Re-evaluation of the SMKT bin sizes.
2. Consolidation of the SMKT inventory with the warehouse
3. Prioritization of picking and assembly procedure based on available manpower

The second strategy is further divided into two directions to focus on different aspects of the consolidation process.
Vijay’s work [5] focuses on identifying the underlying causes for material shortages in the SMKT and includes recommendations to overcome these shortages. The inventory consolidation strategy is the collective effort of R. Xu and Zhang. The writer’s thesis focuses on the analysis of required floor space for projected capacity expansion, the utilization impact analysis for docks and trucks, and the cycle time impact analysis using the FlexSim simulation software. The thesis presents time studies on various stages of the SMKT production process and fits distributions to the available data. The thesis also presents a financial analysis to determine the annual savings for implementing this operational change. Zhang’s thesis [6] focuses on the analysis of floor space requirement in the warehouse to accommodate the SMKT inventory and the new inventory picking process. In addition, this thesis also goes into great depth to describe the details of implementation and provides solutions to the potential challenges during the implementation. Z. Xu’s [7] thesis concentrates on analyzing the current capacity in the SMKT area, creating a matching algorithm with corresponding GUI to generate a work plan for the SMKT sub-assembly process, providing recommendations in terms of data acquisition and utilization, and resources management.

Chapter 2 of this thesis provides a detailed description of the current operation at Varian and discusses the impact of late SMKT delivery. Chapter 3 presents the methodology the MIT used for data collection and analysis. Chapter 4 interprets the data collected in Chapter 3 to explore the sources of the shortages. Chapter 5 presents a proposal for an inventory consolidation strategy to resolve the SMKT shortage problem, taking into account the prevailing market conditions. Chapter 6 presents the detailed implementation plan for the recommendation. Chapter 7 attempts to brings the work of all members together into a cohesive overall strategy for Varian. Chapter 8 points out the future work that needs to be done.
2. Technical Background Information

Varian has a complex manufacturing line, making highly customizable products. Each Tool consists of several thousand parts, and subassemblies. They are also large and heavy, on the order of 30 feet and 20 tons.

2.1. Terminology

2.1.1. Product & Components

- **Tool**: A Varian product that typically fall into the category of high current, medium current, and high energy. Each Tool has several MODs and one UES.
- **MOD**: Modules that go onto the Tool. Modules are usually different depending on the category of the Tool.
- **UES**: The Universal End Station of the ion implanter, a large assembly similar in scale to the Modules. It is used across the majority of Tools.

2.1.2. Physical Production Space

- **Flowline**: A generic name for the production floor space where MOD, UES and other Tools are built and tested.
- **SMKT**: Short for the Supermarket, an inventory storage and sub-assembly production and testing area adjacent to the MOD and UES Flowlines.

2.1.3. Existing Practice

- **Coversheets**: The cover of a shop order. It specifies the print date, start date, and part number if there is a shortage. An example can be found in Appendix A.
- **Shop Order**: A list of items that needed to assemble a SMKT sub-assembly.
2.1.4. Current Technology

- SAP: The primary enterprise system used at Varian to automate and track a variety of operations. Examples of the operations include material management, forecasting, and finance.
- EWM: The Extended Warehouse Management System is a secondary enterprise system used for specifically material management in the Warehouse setting.

2.1.5. Event Category

- SMKT shortage: The event that a part needed for a SMKT sub-assembly build is not available during picking.
- Picking: The act of picking items on a Shop Order.
- Late SMKT sub-assembly: Late delivery of SMKT sub-assembly to the Flowline
- Late Z-pick: Late delivery of part or sub-assembly by the Warehouse or suppliers to the Flowline
2.2. Current Material Flow

The Material Flow in Figure 2-1 shows a block diagram that visualizes the material flow within Varian. It covers the material movement between three Varian locations:

- Warehouse (i.e. BLDG 80)
- Secondary Warehouse (i.e. BLDG 70)
- Main Building (i.e. BLDG 35)

![Figure 2-1: Current Material Flow Diagram](image)

2.2.1. Warehouse and Secondary Warehouse

The Warehouse and the Secondary Warehouse serve as Varian’s main bulk material receiving and storage locations. Most of the incoming parts from suppliers around the world are received at the receiving docks of the Warehouse and Secondary Warehouse. There are also a number of items delivered directly to the Main Building, and stored in SMKT. Parts delivered to Secondary Warehouse and Warehouse are warehoused in different locations depending on the part size and space availability. Secondary Warehouse typically stores very large and heavy parts. Warehouse has four main stocking locations: RK Racks, GL Racks, Vertical Lift Modules (VLM) and Minmax Vendor
Managed Inventory (VMI). Bulky parts are stored in RK Racks; small to medium sized parts are stored in the GL Racks and VLM locations; small to medium sized parts are also stored at the Minmax VMI location, but these parts are managed exclusively by the suppliers. The VLM is an automated storage and retrieval system that enables better picking efficiency and storage efficiency than the GL Racks.

Apart from being stocked away, parts can also go through inspection. Parts that fail inspection will be sent back to the suppliers. In addition, there are shortage parts that are needed on the Flowline and SMKT. These shortage parts will be put in the Cross Dock area, and transported to other Varian facilities by the next truck. Parts from Cross Dock can be delivered to SMKT, or directly to Flowline.

The Kit Room consolidates items, such as harnesses, which are used only at the customer location to assemble the MOD and UES into a working ion implanter. Kits from Kit Room are packed and delivered to Warehouse receiving dock. The kits will be shipped to customer along with the Tool.

2.2.2. Main Building

In the Main Building, there is the SMKT inventory area, the MOD inventory area, and the Minmax area. The SMKT also consist of a sub-assembly area, where piece parts are used to build subassemblies. These piece parts come from three sources: Warehouse for rarely used or bulky items (i.e. CO27 items), SMKT inventory, and Minmax. After subassemblies are completed, they can go to the Flowline, be put onto the Gold Square (GS) shelves, or shipped directly to customers.

The Flowline is where MOD and UES are built and tested. After building and testing, the modules will be packed and delivered to customer, and be installed in customer’s side. Inputs to the MOD/UES Flowlines include bulky parts from Secondary Warehouse, consolidated MOD kits in Main Building, GS from the SMKT, SMKT subassemblies from the Main Building, SMKT inventory from the Main Building, and Cross Docked items from the Warehouse.
2.3. Information Flow

The block diagram of information flow is shown in Figure 2-2. The area within the dashed rectangle refers to the SMKT. The material procurement is driven by the Material Resource Plan (MRP). MRP is based on the demand forecast for Tools and a production schedule. Marketing department makes sales forecast based on historical data, and generates a production schedule forecast for material procurement. The Tool production is based on the confirmed production schedule when a customer places an order.

When an order is placed, the lay-down day for the modules is known. Varian then sets the shop order release date for sub-assemblies five days before the Tool lay-down day. Let \( T^* \) be the Tool lay-down day and \( C \) the shop order release day. Then \( C = T^* - 5 \). Planners release the shop orders by printing them and put them in a pile of shop orders in the SMKT sub-assembly area for pickers to pick up. Planners prioritize the picking by changing the sequence of the printed shop orders. The shop orders are usually picked from the top of the pile, but this practice is not enforced. The shop order gives pickers the information on the type of inventory to pick. There are three types of inventory for a shop order: SMKT inventory, CO27, and Minmax.

![Figure 2-2: Current Information Flow Diagram](image-url)
SMKT inventory and Minmax are stored and picked in the Main Building. CO27 parts are stored in the Warehouse, and a signal to request the part is only sent to the Warehouse when the shop order picking begins. The SMKT inventory and Minmax follow different replenishment policies as shown below.

SMKT inventory can be further divided into three categories: EWM driven Minmax parts, Primed parts, and Kanban parts. When the quantity of EWM driven Minmax parts falls below a preset minimum level, an automatic replenishment signal is sent to the Warehouse for parts to be transferred to the SMKT. In addition, if the EWM driven Minmax parts are depleted before the replenishment arrives, pickers send a separate signal to request for the part for the shop order they pick. If the Warehouse is out of stock for the required parts, Varian will contact the suppliers to expedite the replenishment delivery. Primed parts are parts driven by MRP, and they are likely one-off purchases, and do not have a fixed bin size in the SMKT. Kanban parts operate under a two-bin Kanban system.

Minmax are separately managed by Varian and vendors based on the part types. Varian managed Minmax parts in the SMKTs are replenished through visual inspection. Two pickers are responsible for visually checking the quantity of these Minmax parts in the bins. They will send out replenishment signals when the quantity of the Minmax bin drops to the threshold for reordering. VMI Minmax is inspected once a week by the vendor. A sticker inside the bins indicates the reordering quantity. The vendor will estimate the quantity of Minmax. There are 12 inventory replenishment every year.

After a kit is picked to complete, the production lead decides which kits to assemble based on the actual date the sub-assemblies are need. Sales department updates the Tool shipment day, because customers may change the date by pushing it back, or moving it earlier, although the latter rarely happens. If a customer pushes back the ship day, the lay-down day for the Tool is also pushed back. However, this change in actual shipment day does not alter the MRP planning dates. Let T be the actual lay-down day of a Tool. Then T* and T may be different. Nevertheless, the production lead checks the actual need
date for the sub-assemblies and decides when the shop order should be assembled to keep the production on schedule.

During production, a material request may be sent when the required parts is missing or defective. This information feedback process from the downstream is called Window Requisition (Window Req) at Varian and it applies to both the shop order sub-assembly and line assembly. The Window Req information is sent to location responsible for storing the part. If the material is stored in the SMKT, the Window Req is fulfilled by pickers. Otherwise, it is fulfilled by the Warehouse, or Secondary Warehouse.

If a sub-assembly is not delivered on-time to the Flowline, Flowline production leads will send a request for the sub-assembly. They will also send a request for a replacement if the sub-assemblies delivered is defective or damaged. On the other hand, if a piece part component from the Warehouse is out of stock, the information for cross-docking is generated to fulfill the shortage when the material arrives at Varian.
2.4. Impact of SMKT Subassemblies Late Delivery

2.4.1. UES

The MIT team obtained the shortage data for UES from emails sent by the UES lead twice a day. In the emails, the production lead lists out the SMKT sub-assemblies, and the piece parts from the Warehouse that are not delivered on-time. The piece parts can be a small component, or a large sub-assembly. The lead considers a sub-assembly to be late if they are not delivered on the lay-down day. Lay-down day means the first day on which a module starts to be build. According to the Annual Operational Performance (AOP) Goal set by Varian management, the average build and testing time for a UES module is 4.5 days and 4.5 days respectively. One UES module is built simultaneously in six separate sub-modules, all of which start to be built on the lay-down day. Four of the sub-modules can be completed in one day, and the other two takes two days to build. Despite the goal of 4.5 days for build, a UES module can theoretically be built to complete in two days if the factory is at its full capacity and there is no part shortage. While most of the components are needed on the lay-down day, some component parts of sub-modules that takes two days to be build are actually needed on the second day. The actual need day of a component is used to calculate the actual impact of a late part on the production of Tools.

The email of shortage data was tracked from May 26th to July 21st 2017. Only UES modules that were lay-down, and completed within this period were considered. Four modules were idle for a period of time and are excluded from the analysis, because the idle time gave the SMKT additional time to build the sub-assemblies. 29 UES modules were analyzed. The actual cycle time for build and test are 5 days and 7 days, respectively. This is longer than the AOP goal of 4.5 days for either build and test, and significantly longer than the theoretical build day of two days. The assembly of UES modules follows a critical path. When a component part is delivered late to the assembly, the assemblers have to work out of sequence and assemble the other components because assemblers do not sit idle to wait for the missing part to arrive. When the part arrives, the assemblers need to disassemble some components to install the late part. Then they put the disassembled parts back to the module. This process not only incurs
extra working hours, but also increases the probability of failure because of the repetitive steps of assembling, disassembling and re-assembling. Elyud argued in last year’s MIT thesis that material shortage forces assemblers to work out of sequence, which leads to lower FPY[8].

Figures 2.3 and 2.4 show the average delay of the SMKT sub-assemblies for UES and the number of occurrences of the delay for each assembly type. The assembly types are disguised for reasons of confidentiality. SA means sub-assembly and GS means gold square. Each SA is a generic group for that type of sub-assembly with different configurations. The actual need day of a certain type of assembly does not change despite the configurations. The blue bars at the bottom for SA21-SA26, GS5 and GS6 indicate that these subassemblies are needed on the second day. SA1-SA20 and GS1-GS4 are needed on the lay-down day. Out of the 29 completed modules, 17 started testing process with at least one SMKT part short. 9 out of the 29 modules have SMKT sub-assemblies as the last part to arrive. SA25 is a common sub-assembly that goes into every UES module and it is needed on the second day of build. This subassembly has on average the third longest delay of six days after the actual need day. In addition, it was short for 26 UES modules out of the 29 modules that were build. Six gold square sub-assemblies also appeared in the shortage list. Two of them are delayed for 4.5 days on average. Although GS sub-assemblies are built to be safety stock, it gets depleted in some occasions. This means when a gold square is taken from the rack for production, the SMKT does not start building a replenishment immediately. The delay of the SMKT sub-assemblies reflects SMKT’s inability to operate in accordance with production schedule.
Figure 2-3: Average Delay of SMKT Sub-assemblies for UES

Figure 2-4: Delay frequency of SMKT sub-assemblies for UES
2.4.2. Material Rework

Shortage problem is leading to problems downstream. On the Flowline, material shortage leads to rework (i.e. RMat Rework). The shortage can be due to two reasons: late z-pick, or late SMKT sub-assembly. The definition of two types of shortages are explained previously under Section 2.1. When there is a material shortage, the workers have to work around the missing component. However, when the missing component finally arrives, the assembler has to take apart the bulky module to install it.

An analysis of the Production Tool Labor Hour Report over the duration February to May 2017 reveals that out of 73 Tools—only Medium Current, HCP, HCS and Tridents are considered—built during that period, rework due to material shortage takes on average 22.2 labor hours per Tool. In Figure 2.5, the figure on the left shows the cost of RMat Rework per Tool for four product categories. Taking into account the fact that each product category has a different demand, the weighted average cost is $2,147 per Tool. Figure on the right shows the total RMat Rework cost per quarter for each product category. Combining the four product categories, the total RMat Rework cost per quarter that Varian incur is $156,730.

Figure 2-5: Financial Impact of Material Shortage
There is not enough data to determine the proportion of short Z-pick to short SMKT sub-assembly. A sensitivity chart is created to explore the financial impact of this proportion. From qualitative data, the proportion of a short SMKT sub-assembly is logically around 50%. As such, the rework labor hours due to SMKT shortage per Tool will be:

Total rework hours due to material short*Proportion of a short due to SMKT sub-assembly

\[ = 22.2 \text{h/Tool} \times 50\% \]

\[ = 11.1 \text{h/Tool} \]

As such, the financial cost of rework labor hours due to SMKT Subassemblies Late Delivery per year will be:

Total rework hours due to SMKT Subassemblies Late Delivery*Hourly Labor Cost*Production Output

\[ = 11.1 \text{h/Tool} \times $100/\text{h} \times 280 \text{Tool/year} \]

\[ = $311,749/\text{year} \]

Table 2-1: Cost Savings from Reducing RMat Rework

<table>
<thead>
<tr>
<th>Total RMat Rework Time per Tool (SMKT &amp; z-pick)</th>
<th>22.2</th>
<th>h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of shortage due SMKT</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>Total Rework Time Saved</td>
<td>11.1</td>
<td>h</td>
</tr>
<tr>
<td>Hourly Rework Cost</td>
<td>$100</td>
<td></td>
</tr>
<tr>
<td>Production output</td>
<td>280</td>
<td>Tools/year</td>
</tr>
<tr>
<td>Total</td>
<td>$311,749</td>
<td></td>
</tr>
</tbody>
</table>
Table 2-2: Sensitivity Analysis of Proportion of SMKT Late Deliveries resulting in RMat Rework

<table>
<thead>
<tr>
<th>Proportion of SMKT Late Deliveries resulting in RMat Rework</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsequent Net Savings (Per Annum)</td>
<td>$187,050</td>
<td>$249,399</td>
<td>$311,749</td>
<td>$374,099</td>
<td>$436,499</td>
</tr>
</tbody>
</table>
2.5. Sources of shortages

2.5.1. GL Shorts

GL shorts are typically self-inflicted shorts. This means that the shorts are internal to Varian. Three types of shorts—Transfer, Minmax and CO27—are the result of having two inventory storage locations: SMKT and Warehouse. For the writer’s subsequent analysis, he will refer to these three types of shorts as Duo-Locatin Shorts. The possible categories of GL Shorts are listed below in Table 2-3.

Table 2-3: Description of Type of GL Short

<table>
<thead>
<tr>
<th>Type of GL Short</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer</td>
<td>Transfer bins, which contain the Transfer parts, are replenished by the Warehouse. The short occurs when the Transfer item is not available in the SMKT during picking, but stock is available in the Warehouse.</td>
</tr>
<tr>
<td>Minmax</td>
<td>Minmax items are consumables used on SMKT sub-assemblies. The short occurs when the Minmax item is not available during picking, but stock is available in the Warehouse.</td>
</tr>
<tr>
<td>CO27</td>
<td>CO27 items are rarely-used or bulky parts that are not stored in SMKT. The part has to transferred over from Warehouse every time it is needed for a shop order. This is considered a short, because the item is not there during picking.</td>
</tr>
<tr>
<td>Quality</td>
<td>The part is short in the SMKT and Warehouse, but units of the part are present in the Quality Department for review.</td>
</tr>
<tr>
<td>Inspection</td>
<td>The part is short in the SMKT and Warehouse, but units of the part are present in the Inspection Department for review. This includes parts that have to go through inspection before stocking.</td>
</tr>
</tbody>
</table>
2.5.2. Real Short

A real short for the most part refers to a supplier short. This will be external to Varian. The possible categories of Real Shorts are listed below in Table 2-4.

Table 2-4: Description of Type of Real Short

<table>
<thead>
<tr>
<th>Type of Real Short</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minmax VMI</td>
<td>Minmax VMI are Minmax items managed by vendors. The short occurs when the Minmax VMI item is not available in the SMKT during picking.</td>
</tr>
<tr>
<td>Minmax Actual</td>
<td>Minmax Actual refers to a supplier short. If the short part is a Varian free stock part and if stock is unavailable in the Warehouse.</td>
</tr>
<tr>
<td>Actual</td>
<td>The short part is neither Minmax VMI nor Minmax Actual, and no stock is available at the Warehouse.</td>
</tr>
<tr>
<td>CO27 Actual</td>
<td>The short part is a CO27 part, and no stock is available at the Warehouse.</td>
</tr>
<tr>
<td>Sales</td>
<td>A special case of the shortage listed in Actual. This is when shortage of parts is a result of a Sales order depleting the bins in the SMKT. The deduction is usually done by looking at the material movements in SAP. It is possible to tell that if a material is picked for a Sales order.</td>
</tr>
</tbody>
</table>

It should also be pointed out that when the template was initially proposed, a distinction between Minmax and Minmax Actual was not recorded. If a short part was of Minmax type, it was recorded under the GL column. This was due to the nativity of the team in thinking this distinction was not important during the early stage of this project. As the overall material movement picture became clearer, this information was deemed important and subsequently recorded. This was the same case for CO27 and CO27 Actual Causes.
3. Methodology

3.1. Interviews

Many interviews were conducted with managers and workers. The interviews fall broadly into two categories: formal, and informal. In the beginning, most interviews were scheduled as a team. As the team started working on their individual recommendations, the interviews became a mix of formal and informal.

Interviews are a good way to gain clarification on a high level. Examples include how the firm decides to replenish its material, how the firm manages its Window Reqs, and how the firm transport its material. The employees are Varian are very helpful in providing supporting information to confirm their assertions.

3.2. Data Collection

3.2.1. Daily On-site Inspection

Before the team embarked on the project, Manufacturing Engineer Adam Vigneault has been collecting data on the SMKT shortages. From February to May 2017, the team was only able to work part-time at Varian. Vigneault was kind enough to help collect the data over the period. The data was collected in-person by looking at short kits lined up at the SMKT inventory area. A template was created by the team to allow the data to be collected in a comprehensive manner (see Table 3-1). A sample of the data is shown in Table 3-1. Once the team started working full-time in June 2017, the data is collected Monday to Friday at 3:30pm by the team over the period June 1st to July 12th 2017.

Table 3-1: Proposed Template for Daily On-site Inspection Data Collection

<table>
<thead>
<tr>
<th>Date</th>
<th>Type of Order</th>
<th>Assembly No.</th>
<th>Description</th>
<th>S/O No.</th>
<th>Due Date</th>
<th>S/O created</th>
<th>GL Shorts Qty</th>
<th>GL Short Part no.</th>
<th>GL Short Cause</th>
<th>Real Shorts Qty.</th>
<th>Real Short Part No.</th>
<th>Real Short Cause</th>
</tr>
</thead>
</table>
3.2.2. SMKT Kit Coversheet

SMKT Kit Coversheet was originally created by SMKT Supervisor Brian McLaughlin. It has been used in SMKT for tracking shop order status, and for inventory management. It contains the detailed shop order information regarding the type of order, the subassembly number, the quantity and the description. It also records the time when the shop order is released and the planner who released it. Pickers will fill out the date and time when he/she finishes picking one kit to complete, otherwise the information about short parts will be noted down. Assemblers will write down their name, date and time when they start building. When a subassembly is built to complete, assemblers also note down the finish date and time. Unfortunately, the policy of recording data is not enforced among workers. It is common that SMKT Kit Coversheets are left blank. The SMKT Kit Coversheet was revised by MIT Team (see Appendix A). An addition is the shop order start picking time.

Kit coversheets are gathered from SMKT every day with the help of planners John Pratt and John Davis. The information for each shop order is documented in one Excel file by the MIT Team. Thanks to the data input from all pickers and assemblers in the SMKT, the MIT Team was able to collect a complete data set of SMKT shop orders from May 26th to June 26th 2017.

3.2.3. Enterprise System

SAP is the enterprise software at Varian that is employed to automate and track a variety of operations. The EWM platform in SAP, provides additional inventory management solutions. Among the numerous capabilities of this software package, the most relevant ones are listed below:

- View Bill of Materials for different Tools, sub-assemblies and piece parts
- Provide up-to-date, or specific-to-date information on materials including and not limited to quantities at various locations, requirements for different applications, and sourcing information of the material.
- View all the transactions of parts in Varian (or at specific stock location) and provide information including and not limited to date of transaction, purpose of transaction and quantity of transaction.

Inputting different ‘SAP Codes’ allows the information described above to be obtained. The Team heavily relied on SAP, during the shortage data collection phase, to correctly identify causes of shorts for parts on a given day. The categorization of shortages into GL or Real as defined by the Team was only possible after looking up relevant information for the part on SAP. The process involves first identifying whether the part is of type SMKT Bin, Minmax, or VMI. If the part is VMI, it is directly recoded under the Real Cause column. If not, stock availability for the part in the Warehouse is cross-referenced. If no stock is present in the Warehouse, the part is listed as either Actual or Minmax Actual respectively. However, if stock is available in the Warehouse, the shortage cause is either Transfer or Minmax respectively.

Table 3-2 below summarizes the periods over which data was collected along with information on the individual/software that collected this data, the format used to log the data, and the source of data.

Table 3-2: Summary of Data and Data Sources

<table>
<thead>
<tr>
<th>Period of Collection</th>
<th>Collector</th>
<th>Format</th>
<th>Source of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb 2- Feb 10</td>
<td>Mfg. Eng.</td>
<td>Old</td>
<td>SMKT BuildLog</td>
</tr>
<tr>
<td>Feb 21-Mar 3</td>
<td>Mfg. Eng.</td>
<td>Old</td>
<td>SMKT BuildLog</td>
</tr>
<tr>
<td>Mar 8- Mar 31</td>
<td>Mfg. Eng.</td>
<td>Old</td>
<td>SMKT BuildLog+ SAP Movements</td>
</tr>
<tr>
<td>April 4- May 5</td>
<td>Mfg. Eng.</td>
<td>New</td>
<td>SMKT BuildLog+ SAP Movements</td>
</tr>
<tr>
<td>Time Period</td>
<td>Team</td>
<td>New</td>
<td>Documentations</td>
</tr>
<tr>
<td>------------------</td>
<td>---------------</td>
<td>-----------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>May 15 - June 8</td>
<td>MIT Team</td>
<td>New</td>
<td>Cover Sheets + SAP Movements</td>
</tr>
<tr>
<td>Jun 1 - Jun 26</td>
<td>MIT Team</td>
<td>New</td>
<td>Cover Sheets + Daily Inspection + SAP Movements</td>
</tr>
</tbody>
</table>
4. Numerical results and Interpretation

4.1. Analysis of SMKT Shortages (Part Level)

The Daily On-site Inspection data—with the help of SAP—shows that the shortages appear to be one-off random events. The Daily On-site Inspection data was analyzed for the duration February 2\textsuperscript{nd} to June 13\textsuperscript{th} 2017.

A shortage problem that is potentially easy to tackle will be a Pareto chart showing that 20% of the parts cause 80% of the shortages. However, in the Pareto in Figure 4-1, it is found that 20% of all unique parts causes only 44% of the shortages. In other words, in order to solve the shortage problem, the team has to prevent shorts on a large number of different parts.

![Pareto Chart of Short Parts](image)

Figure 4-1: Pareto Chart of Short Parts

The writer conducted two case studies for the two most commonly short part. The most commonly short part is the E17296280. A large number of shorts occur in the span of days, and the rest of the time there is no shortage. Between April 6\textsuperscript{th} and June 3\textsuperscript{rd} 2017, there were 11 instances of short. There are two major events: first, between April 6\textsuperscript{th} and April 17\textsuperscript{th}, the SMKT bins were depleted for Sales orders, causing seven shortages over
the 11 days; second, between June 1\textsuperscript{st} and June 3\textsuperscript{rd}, a late replenishment of the Warehouse bin caused three Transfers and one Actual Short. A timeline can be found in Figure 4-2.

![Timeline of Short for E17296280](image)

For the second most commonly short part—E17783100—the case is in fact only one isolated event. All seven shortages occurred within a span of 3 days between March 29\textsuperscript{th} and March 31\textsuperscript{st}. On March 7\textsuperscript{th}, 50 units of the Feedthru were received. On March 28\textsuperscript{th}, 25 Feedthru failed inspection, and had to be return to the supplier; 22 of the Feedthru passed inspection, and had to wait to be transferred to the Main Building. On March 29\textsuperscript{th}, three shop orders needed the Feedthru, but the parts were still in the Warehouse. Between March 29\textsuperscript{th} and March 30\textsuperscript{th}, any remaining demand was satisfied by the 22 units that passed Inspection. However, by March 31\textsuperscript{st}, the 22 units were all used up, and four more kits ran short. Logically speaking, there should be three units still inspection. A timeline is shown in Figure 4-3.
With the part shortages appearing like one-off random events, there is insufficient data to create a robust predictive algorithm. It will take years to come up with enough data to predict when a SMKT part, and by extension a SMKT sub-assembly, is likely to be short. With a rapidly-progressing semiconductor equipment landscape, the team needs to move fast, and change the system to make a real impact.
4.2. Analysis of SMKT Shortages (Assembly Level)

Using the Daily On-site Inspection data over the period Feb 2\(^{nd}\) to June 13\(^{th}\) 2017.

Figure 4-4 shows the most frequently short sub-assembly kits. Figure 4-5 shows the most frequently demanded sub-assemblies. One observation is that the most frequently short sub-assembly kit does not have to be the most frequently demanded sub-assembly. For example, even though the EPM Lens is made 30% more frequently than the Profiler, the Profiler is 3.6 times more likely to be short than the EPM Lens. This is clearer when one looks at the probability of short for top 10 most commonly short sub-assembly kits normalized by their demand (see Figure 4-6). This piqued the writer’s interest in the Profiler, and the list of other commonly short sub-assemblies. One can also conclude that there are many variables at work when causing a shortage.

![Figure 4-4: Most Frequently Short Sub-Assembly Kits](image-url)
Figure 4-5: Most Frequently Demanded Sub-assemblies

normalized probability of a short = \( \frac{\text{number of short}}{\text{total demand}} \)

Figure 4-6: Normalized Demand of Most Frequently Short Sub-assemblies
4.3. Main Causes of SMKT Shortage

The main causes of SMKT shortage are visualized using pie charts. These pie charts are created using the Coversheets data. The Coversheets data is the most complete data that the MIT team has collected over the span of the project. It tracked 95% of the kits that SMKT built between May 26th to June 26th 2017.

From the STD Labor Hours data from December 2016 to June 2017, the average kit is on-time 61% of the time (see Figure 1-5). This drops to only 37% when the kit is short (see Figure 4-7).

![On-Time Delivery of Short Sub-assemblies (Feb - June 2017)](image)

Figure 4-7: On-Time Delivery of Short Sub-assemblies
There are two broad categories of shorts: GL and Real. Nearly two-thirds of the shorts are GL shorts (see Figure 4-8). The specific breakdown can be found in Figures 4-9, which uses the Coversheet data. There are 393 observations.
The team presented the findings to Varian’s management, and was urged to focus on the causes of GL shorts. To recap, the GL short causes includes Transfer, Minmax, CO27, Inspection and Quality. These are deemed easier to remedy, because of they are internal to Varian. Problems that exist within the company can be more actionable. The Real short causes will concern suppliers, and will involve negotiations between Varian and the suppliers. This may not be actionable for the MIT team, and will be out of the scope of our project. As such, the MIT team decided to focus on GL shorts.
5. Recommendation

5.1. Consolidated Inventory Strategy

The inventory consolidation strategy is the collective effort of Zhang and the writer. Refer to Section 1.4 for the division of work. The strategy involves storing all current Non-Minmax SMKT line items, and an appropriate amount of Minmax items in the Warehouse, instead of the SMKT (see Zhang’s thesis [6]). This will allow Varian to eradicate 64% SMKT’s shortage, save an estimated $467,488 per annum, and free up 3,000 ft² of production space for Varian to expand its capacity. Under the consolidation strategy, SMKT kits will be picked at the Warehouse, and only complete kits will be transported to the SMKT assembly area in the Main Building for assembly and testing. This will save 3,840 labor hours currently spent on repetitive tasks.

5.2. Goals

There are four goals of the consolidation strategy:

(1) Fewer SMKT shortages
(2) Shorter Cycle Time
(3) Net Cost Savings
(4) Floor Space Savings

Fulfilling these goals will allow the SMKT to achieve a better on-time-delivery, improve Varian’s bottom-line, and free up floor space for capacity expansion.
5.3. Literature Review

The creation of the SMKT is the result of the work by another MIT team in 2008. Before 2008, the production floor is divided into several assembly lines that operate in parallel to produce “specific products and specific modules” [9] (see Figure 5-2). The earlier team noticed that while the dedicated lines have the benefit of isolating operational problems in their own lines, knowledge and learning are also localized within each line. Additionally, dedicated lines meant that production output cannot be adjusted fluidly, because each line has a fixed amount of floor space. Treis explains by saying that “a line with rising demand experiences a floor space shortage while a line with dropping demand enjoys excess floor space” [8].

![Google Map image of Important Varian Buildings](image-url)
2008 was a period of low demand for Varian. With the assembly plant running at low utilization, Varian saw this as an opportunity to consider changes in operations and layout. The operational change was supposed to help Varian realize its mid-term goal of increasing revenue by 100% [9]. The earlier MIT team proposed aggregating the sub-
assembly resources to build a common sub-assembly build area, with inventory storage consolidated at the “North Floor” (see Figure 5-3). This evolved into the current SMKT inventory location. The proposal was accepted by the Varian management, and that was the beginning of the current SMKT.

The earlier MIT team had very compelling reasons to consolidate the inventory at the SMKT inventory area. In his thesis, Treis explains “if parts have more than one storage location, they are stored redundantly” [9]. He was referring to Varian’s older inventory management strategy of storing parts specific to dedicated production lines in the Main Building. However, if one takes a step back, even though SMKT’s inventory is now consolidated the SMKT location, there are still two inventory locations: one at the Main Building, and another at the Warehouse. This duo-storage location is leading to current material shortages in the SMKT.

5.4. Floor Space Analysis
With a bullish semiconductor industry outlook, Varian will need the production floor space to increase its capacity in the upcoming years. The expansion between 2018-2019 is predicted increase Varian’s capacity by between 40% to 80%. This will transform the layout at Varian, and new production floor space has to be made available for the expansion.

The capacity expansion plan for the MOD and UES areas in Figure 5-4 is made available to the team by a production manager. The yellow boxes indicate areas that are currently being used for other purposes shown in Figure 5-5. It is worth noting that the potential expansion is expected to be in the range of 40-80% in 2018-2019. The following plan is looking further ahead.
Figure 5-4: Capacity Expansion Plan for MOD and UES Build and Test

Figure 5-5: Current Purpose of Marked Areas
In order to expand from the current 70 Tools/quarter to 150 Tools/quarter, the bottleneck is in MOD and UES testing. New test stands will have to be added (see Table 5-1). The predicted production output is derived from a Python simulation.

Table 5-1: Number of Test Stands Required for Expansion

<table>
<thead>
<tr>
<th>BAYS</th>
<th>90 Mod</th>
<th>Output/Qtr</th>
<th>Output/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>12</td>
<td>86.00</td>
<td>343.98</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>114.66</td>
<td>458.64</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>143.33</td>
<td>573.30</td>
</tr>
<tr>
<td>6</td>
<td>17</td>
<td>172.32</td>
<td>688.32</td>
</tr>
<tr>
<td>9</td>
<td>UES</td>
<td>125.08</td>
<td>500.33</td>
</tr>
<tr>
<td>10</td>
<td>QTR</td>
<td>138.98</td>
<td>555.93</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>152.68</td>
<td>611.62</td>
</tr>
</tbody>
</table>

A floor space survey is carried out. The required floor space for expansion is estimated to be around 3000 ft². This is the same floor area of the current SMKT inventory area (see Figure 5-6). By moving the SMKT inventory area to the Warehouse, there will be enough floor area for capacity expansion.

Figure 5-6: SMKT Inventory Area and Required Floor Space for Expansion

It is worth noting that this analysis did not take into consideration the floor space required for expansion of the SMKT. As such, it is likely that even more floor space will have to be made available to accommodate more SMKT assembly benches.
5.5. Volume Analysis and Time Study (Trucks & Docks)

Under the consolidation strategy, SMKT kits will be picked at the Warehouse. This means that it is necessary to change the format at which material will be transported. It is necessary to consider if the change will cause the trucks or docks to be over-utilized.

5.5.1. Volume Analysis (Transfer Methods)

Currently, material is being transported in three forms: tote boxes, original cardboard boxes, and large bins. These pieces are then placed on pallets, and transported using medium-sized trucks.

Once SMKT kits are picked at the Warehouse, the most straight-forward method will be to transport the items using trolleys that SMKT pickers currently use to pick shop orders with. These trolleys come in two forms: two-level trolleys, or three-level trolleys. Typically, two trays are placed side by side on each level as shown Figure 5-7. In the event that there are already four trays, the picker will stack the additional pick trays on top of the four trays.

![Figure 5-7: a) SMKT Trolleys, b) Positions of Pick Trays and Tote Boxes, c) Wheel brakes to be Installed onto Trolleys when Loaded onto Truck](image-url)
After measuring 19 complete kits in the SMKT sub-assembly area, it is determined that an average SMKT trolley can hold at least 6 trays (two-level trolley; two tray locations on each level; two trays are stacked together at each tray location on the bottom level), or at most 12 trays (three-level trolley; two tray locations on each level; two trays are stacked together at each tray location). If there are no trays on the top level, the top level can hold up to two tote boxes. If the trolley has two levels, then it can also fit two more totes on the bottom level. The trolleys with three levels will not be able to fit any totes on the bottom or medium levels.

In the worst case scenario, two-level trolleys are used, and trays are only stack on the bottom level. Even in this arrangement, on average only 0.598 trolley will be utilized. When CO27 items are included, there is on average an additional 0.659 pallet.

Each pallet measures 48" by 40". Varian uses two medium-sized trucks; each measuring 24' in length by 8.5' in width by 9.08' in height. By lining the long edge of the pallets along the long side of the trucks, it is possible to fit in two columns of six pallets each into one truck. In other words, the capacity of a medium truck is 12 pallets. The trucks are currently used for transporting items between seven Varian locations. In this analysis, the focus will be on the two buildings that will be affected by the inventory consolidation: Main Building and the Warehouse.

From the Coversheets collected between May 26th and June 26th, the average number of kits picked per weekday is 30. As aforementioned, each kit is equivalent to 0.598 trolley and 0.659 pallet. Assuming that trolleys will not be combined, each kit is then equivalent to 1 trolley and 0.659 pallet. The number of transfers required will be:
# of transfers required

= 1 transfer for 21 trolleys
+ 1 transfer for 6 trolleys & 8 pallets
  + 1 transfer for 12 pallets
  + 1 transfer for 3 trolleys (at 7% utilization)

= 3.07 transfer/day *(inc. CO27)*
5.5.2. Time Study (Docks & Trucks)

A time study is done to determine the time required at each step of the transfer process (see Table 5-2). A typical truck transfer process is as follows:

![Truck Transfer Process Diagram]

Figure 5-8: Truck Transfer Process

Table 5-2: Time Study of Loading and Unloading at Main Building & Warehouse

<table>
<thead>
<tr>
<th></th>
<th>SMKT</th>
<th>Warehouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading Time</td>
<td>1min/pallet</td>
<td>1.5min/pallet</td>
</tr>
<tr>
<td>Opening + Closing Dock</td>
<td></td>
<td>1min</td>
</tr>
<tr>
<td>Driver Embarking + Disembarking</td>
<td></td>
<td>3min</td>
</tr>
<tr>
<td>Driving Time</td>
<td></td>
<td>4.5min</td>
</tr>
<tr>
<td># of trucks</td>
<td>2 Trucks (12 Pallets, or 21 Trolleys each)</td>
<td></td>
</tr>
</tbody>
</table>

At the Warehouse, the loading time is longer. This is mainly because the driver has to personally do the loading. During the loading of each pallet, the driver has to scan all the barcodes (i.e. the Holding Units of items) on the pallet, before using the forklift to bring the pallet into the truck. At the Main Building, there are workers to help the driver unload each pallet. This means that the driver can use this freed up time to scan the pallets he will has load up, resulting in a shorter loading time.

In addition to a time study, data is also collected for the movement of trucks. The data was collected over the span of a week from July 14th to July 20th 2017 at SMKT's loading...
dock (i.e. RD35). It is difficult to obtain accurate data, because the process has to be measured manually throughout the day, and the data logging has to depend on the initiative of the workers at the dock. Nevertheless, four out of five days are deemed to be accurate enough to analyze.

Using the data from the four good days, the utilization of the trucks is determined, by dividing the number of pallets over the truck's capacity. The average truck utilization is 53%. The average frequency of trucks is 11.25.

By combining the time study with the utilization and frequency figures, an estimate of the arrival and departure time of the trucks is obtained at both the Main Building and the Warehouse. This is further used to estimate the utilization of the docks (see Table 5-3).

Table 5-3: Frequency and Utilization of Docks at Main Building and Warehouse

<table>
<thead>
<tr>
<th></th>
<th>Main B1g</th>
<th>Warehouse</th>
</tr>
</thead>
<tbody>
<tr>
<td># of docks for Varian trucks</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Frequency/day</td>
<td>11</td>
<td>11 (estimate)</td>
</tr>
<tr>
<td>Utilization/dock</td>
<td>14%</td>
<td>34% (estimate)</td>
</tr>
</tbody>
</table>

5.5.3. Estimating New Dock Utilization

With reference to Tables 5-2 and 5-3, the Warehouse has only one dock, and a longer loading time. This indicates that the Warehouse dock can be a potential bottleneck. From the volume analysis in Subsection 5.5.1, it is determined that each kit on average is equivalent to 1 trolley and 0.659 pallet. Since there is demand for 30 kits per day, this is equivalent to 30 trolleys and 20 pallets. Assuming the unlikely worst case scenario, where all 30 kits have to be transported, on top of the current SMKT replenishments. The following calculations are done to determine if the Warehouse dock will be over-utilized.
Time Required for Loading 30 Complete Kits @ Warehouse

\[= \text{Doors} \times \text{Number of Transfers} + \text{Loading Time} + \text{Driver} \times \text{Number of Transfers}\]

\[= 1\text{min} \times 4 + \frac{1.5\text{min}}{\text{pallet}} \times 20\text{pallets} + \frac{1.5\text{min}}{\text{trolley}} \times 30\text{trolleys} + 3\text{min} \times 4\]

\[= 91\text{min}\]

New Utilization of Warehouse after Consolidation (Worst Case Scenario)

\[= \frac{\text{Current Dock Utilized Time} + \text{Additional Time Required}}{\text{Dock Open Time}}\]

\[= \frac{4h + 1h31min}{12h} = 46\%\]

Since the utilization of the dock is less than 100%, it indicates that the dock at Warehouse will not be blocked, even in the worst case scenario.
5.5.4. Estimating New Truck Utilization

Assuming the unlikely worst case scenario, where all 30 kits have to be transported, on top of the current SMKT replenishments. The following calculations are done to determine if the trucks will be over-utilized.

Number of Extra Trolleys Trucks can Hold per Day
= Current Truck Frequency*(1-Current Utilization)*Truck Capacity
  = 11transfers*(1-53%)*21trolleys/transfer
  = 109 trolleys

Number of Trolleys required
  = 30 trolleys

New Utilization
= 53% + \frac{30\text{trolleys}}{109\text{trolleys}}*47%
= 66%

Number of Extra Pallets Trucks can Hold per Day
= 11transfers*(1-66%)*12pallets/transfer
= 45 pallets

Number of Pallets required
  = 20 pallets

Final Utilization
= 66% + \frac{20\text{pallets}}{45\text{pallets}}*34%
= 81%

Since the utilization of the trucks under the worst case scenario is less than 100%, it indicates that the trucks will not be over-utilized.
5.6. Cycle Time Analysis (FlexSim Simulation)

Short cycle times usually allow a company to achieve faster time-to-market, and lower work-in-progress. In order to investigate the impact of the inventory consolidation strategy on the cycle time, two FlexSim simulation models are created to compare the cycle time with and without a consolidated inventory location. FlexSim is a discrete event simulation software package that allows the user to combine model units, such as machines, pickers, and production sources, to simulate the operations of a production line.

5.6.1. The Profiler

Currently, the SMKT makes hundreds of different sub-assemblies, and stores 5,480 unique types of parts in the SMKT inventory area. In contrast, FlexSim only allows a maximum of 30 model units of machines, pickers and sources in the simulation. As a result of such limitation, only one type of sub-assembly is simulated: the Profiler. The list of Profilers aggregated in this analysis is summarized in Appendix B. The list deliberately excludes Faraday Assembly, because it is only a component of the overall Profiler assembly.

The Profiler is a critical piece of equipment that measures the current profile of an ion beam. It falls broadly into two categories: In-Vacuum, and Non-Vacuum (i.e. Rack and
Pinion). The Profiler is used on nearly every Tool that Varian manufactures, and is typically the last piece of SMKT assembly to be put onto the UES. However, the track record of the Profiler is very poor. The Profiler is picked to short 93% of the time, and is late 83% of the time (see Figure 5-10). This makes it the most commonly short sub-assembly kit, and one of the sub-assembly that is always late.

![Late Profiler Kits (Sep 16-July 17) and Short Profiler Kits (15th May-26th June)](Source: Brian's Labor Hours sheet 7.17, Coversheets 5.26-6.26)

Figure 5-10: Profilers' Poor Track Record

The UES delay analysis carried out by Zhang tracks the last piece of SMKT sub-assembly that reaches the UES Flowline [6]. Figure 5-12 shows the total number of days that the sub-assembly is late between May 26th to July 21st 2017. From Figure 5-11, the Profiler is shown to have a disproportionately large impact on the UES. Over a span of less than two months, the Profiler has been late by 152 days. The next latest sub-assembly is late for only one-third of that duration.
Figure 5-11: Total Number of Days Late (Sub-assembly Level)
5.6.2. **FlexSim**

Of the two FlexSim simulation models created, the first closely resembles the operations of the current SMKT, and the second resembles the operations at the consolidated inventory location.

![Current SMKT](image1)

![Consolidated Inventory Location](image2)

Figure 5-12: FlexSim Simulation Models of Current SMKT and Consolidated Inventory Location

In the simulation, there are four types of model units:

1) **Source**: The model unit that generates a Profiler unit for the SMKT, based on a demand distribution. The demand distribution is found using historical data. There is only one source in my model: Planner.

2) **Queue**: An infinite area that allows inventory buildup, when the processor that comes after it is in use. These queues prevent the processor that comes before them from being blocked. This is realistic because there is never an occurrence when picker, or assembler should be prevented from doing their task. The queues used in the system include: Shop Order Queue, Shortage Kit Queue, Complete Kit Queue, SMKT Profiler Queue, Window Req Queue.

3) **Processor**: Usually a person, or a machine that performs a certain task on the Profiler. The processing time can be a constant, or follow a distribution. Each
processor can also have two output branches. For example, the picker has a certain probability of picking a Profiler kit to a short, and a finite probability of picking it to complete. These probabilities are assumed to be fixed. The processors used in the two models include in Table 5-4.

Table 5-4: Max Content of Processors

<table>
<thead>
<tr>
<th>Processor</th>
<th>Picker</th>
<th>Replenishment</th>
<th>Truck</th>
<th>Assembler/Tester</th>
<th>Window Req</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Content</td>
<td>1</td>
<td>20</td>
<td>10</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

4) Sink: The model unit that receives Profiler units, without any output. This model unit does not need to be customized. There is only one sink in my model: Flowline.
The inputs to the simulation model are summarized in sequence below:

Table 5-5: Summary of inputs to FlexSim simulation model (Current SMKT)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Mathematical Rep</th>
<th>Source</th>
<th>Number of Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Distribution</td>
<td>Negative Binomial (30.1 hours)</td>
<td>STD Labor Hours 071717</td>
<td>205</td>
</tr>
<tr>
<td>Pick Time</td>
<td>40min/kit</td>
<td>Adam's VSM, Interview with pickers</td>
<td>3</td>
</tr>
<tr>
<td>Picked to Short</td>
<td>93%</td>
<td>Coversheets</td>
<td>27</td>
</tr>
<tr>
<td>Picked to Complete</td>
<td>7%</td>
<td>Coversheets</td>
<td>27</td>
</tr>
<tr>
<td>SMKT Replenishment Time</td>
<td>5.21 days</td>
<td>Coversheets</td>
<td>21</td>
</tr>
<tr>
<td>Assembling &amp; Testing</td>
<td>12.24h</td>
<td>Standard Build Time, Jorge Silveira, Brian McLaughlin</td>
<td>Duration: last 12 months</td>
</tr>
<tr>
<td>Window Req Time</td>
<td>0.29h</td>
<td>SMKT Part Failure Report, SMKT &amp; MOD Mix</td>
<td>62</td>
</tr>
<tr>
<td>Failure Rate</td>
<td>24.6%</td>
<td>SMKT Part Failure Report, STD Labor Hours 070617 &amp; 071717</td>
<td>55 failed out of 224 built</td>
</tr>
</tbody>
</table>

Table 5-6: Summary of inputs to FlexSim simulation model (Consolidated Inventory Location)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Mathematical Rep</th>
<th>Source</th>
<th>Number of Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Distribution</td>
<td>Negative Binomial (30.1 hours)</td>
<td>STD Labor Hours 071717</td>
<td>205</td>
</tr>
<tr>
<td>Pick Time</td>
<td>48min/kit</td>
<td>Adam's VSM, Interview with pickers</td>
<td>3</td>
</tr>
<tr>
<td>Picked to Short</td>
<td>74%</td>
<td>Coversheets, Prediction</td>
<td>27</td>
</tr>
<tr>
<td>Picked to Complete</td>
<td>26%</td>
<td>Coversheets, Prediction</td>
<td>27</td>
</tr>
<tr>
<td>BL80 Replenishment Time</td>
<td>5.75 days</td>
<td>Coversheets, Prediction</td>
<td>21</td>
</tr>
<tr>
<td>Truck Transfer</td>
<td>25.5min</td>
<td>Time Study (average utilization=53%)</td>
<td>2</td>
</tr>
<tr>
<td>Assembling &amp; Testing</td>
<td>12.24h</td>
<td>Standard Build Time, Jorge Silveira, Brian McLaughlin</td>
<td>Duration: last 12 months</td>
</tr>
<tr>
<td>Window Req Time</td>
<td>0.468h</td>
<td>SMKT Part Failure Report, SMKT &amp; MOD Mix, Part Request Analysis (Jan–June 17), Prediction</td>
<td>62</td>
</tr>
<tr>
<td>Failure Rate</td>
<td>24.6%</td>
<td>SMKT Part Failure Report, STD Labor Hours 070617 &amp; 071717</td>
<td>55 failed out of 224 built</td>
</tr>
</tbody>
</table>
5.6.3. Demand Distribution of Profilers

The planners released 205 unique Profilers shop orders over the period of 17th October 2016 to 30th June 2017. This time period is observed to have the most complete data collated by the SMKT supervisor Brian McLaughlin. Using the fitdistrplus library in the data analysis software R, the Cullen and Frey graph is generated. The Cullen and Frey plot allows the data to be fitted to a discrete distribution, based on the skewness and kurtosis of the data [10]. From Figure 5-14, the empirical and theoretical data fits very closely. This allows the writer to conclude that the demand distribution of the Profilers is Negative Binomial with mean 0.8. In other words, there is on average 0.8 of a Profiler shop order released every day. See Appendix B for annotated R code.

![Cullen and Frey graph]

Figure 5-13: Cullen and Frey Graph of Profiler Demand
To use this information in the FlexSim simulation, it is necessary to determine the distribution of the inter-arrival time, based on the demand distribution. The negative binomial distribution is a discrete probability distribution of the number of independent and identically distributed Bernoulli trials until r number of failures. This means that the inter-arrival time—the time between successes—will be geometrically distributed [11]. However, FlexSim does not include geometric distribution as a distribution for inter-arrival time. The next closest approximation is exponential [12]. Hence, the inter-arrival time for Profilers $\sim$ Exponential (30 hours). This means that there is on average one Profiler demanded every 30 hours, or 73 Profilers every quarter. This matches the current production output of approximately 70 Tools/quarter. The small discrepancy is can be attributed to the varied demand of Profilers—not all Profilers are made for Tools; the other possible order types include Spare, Customer Order, and Upgrade.

Figure 5-14: Empirical and Theoretical Distribution of Profiler Demand
5.6.4. Pick Time

There are concerns that the picking time in the Warehouse is longer than that in the SMKT. In Value Stream Maps created by Manufacturing Engineer Adam Vigneault, the time to pick a kit in the SMKT is 40min/kit, and the time to pick a part in the Warehouse VLM is 0.5minute/part (see Appendix D). Since the units are not consistent, and that the average number of parts in the assemblies are hard to determine, time studies were done at both the SMKT, and the Warehouse.

On July 20\textsuperscript{th}, 56 Non-Minmax parts of the Profiler E11641090 were picked by a SMKT picker in 23 minutes. This translates to an average picking rate of 0.42 minute/part. Subsequently, the writer attempted to confirm the quoted picking time of 0.5 minute/part at the Warehouse. However, this attempt proved to be difficult. There are three different places where picking can occur: the GL racks, the RK racks, and the VLM. Time studies were done at GL racks and the RK racks. On the GL racks, 20 replenishments were picked in 1 hour 24 minutes at an average rate of 4.2 minute/replenishment. On the RK racks, 10 replenishments were picked in only 15 minutes, at an average 0.67 minute/replenishment. For the VLM, a time study is not done in person, instead a Spool Request was obtained. On the Spool Request, 8 parts were picked in 13 minutes, at an average rate of 1.6 minute/part.

It does appear that picking at Warehouse is slower than that at the SMKT. But it is important to bear in mind that these pick times vary significantly across pickers. The quantity of items being picked is also different. On SMKT shop orders, each line item typically has a quantity of one. The range is 1 to 50, with the 50 typically being a Minmax item. However, at the Warehouse, during a replenishment pick, the quantity is usually larger. The range is from 1 to 100.

Admittedly, the layout of the Warehouse is not conducive for picking SMKT kits. Improvements can be made to speed things up. Specific plans will be recommended in the Implementation Plan (See Subsection 6.1.2). Since it is more fair to consider the picking rate under the consolidation strategy when such improvements have taken effect,
an assumption is made that the picking rate at the Warehouse—as per Vigneault’s Value Stream Map—is 0.5 minute/part. Compared to only 0.42 minute/part, the picking rate at the Warehouse is 20% slow than the SMKT. The picking rate of a kit at the Warehouse is assumed to by 40 minute/kit*1.2 = 48 minute/kit. A robustness check is conducted in Subsection 5.6.9 to analyze the impact of this assumption.

5.6.5. Percentage of Short Kits

From the Coversheets that were collected, there were 27 Profilers built between May 26th and June 26th 2017. Out of the 27, the 93% of all Profiler kits has one or more shortages (see Figure 5-15). Under the consolidation strategy, the Duo-Location shortages are removed, and the percentage of short Profiler kits will reduce from 93% to 74%. In each case, the picker processor in FlexSim is assigned the above probabilities to pick a Profiler to a short.

Figure 5-15: Percentage of Short Profiler Kits
5.6.6. Replenishment Time

The replenishment time is calculated by taking the difference between the picked-to-complete date and the pick date. This time includes the lead time a supplier needs to deliver the part to the Warehouse, the time the part takes to complete inspection (if any), and the time for cross-docking. Inspection is usually carried out for parts with poor quality track records. Cross-docking refers to the internal process of transferring a shortage from the Warehouse to the Main Building without stocking the item at the Warehouse. The item will be processed at the Warehouse dock for direct shipping to the Main Building.

The Coversheet data is used for this analysis. Out of the 27 Profilers built between May 26th and June 26th 2017, only 21 have the dates recorded on their Coversheets. Out of the 21 shop orders, 19 had shortages. Out of the 19 shortages, 6 were critically short due to Inspection, and 10 were Real Shorts (i.e. Actual Shorts), and the remaining three were due to Duo-Location Shorts.

Inspection, Real Shorts, and Duo-Location Shorts are three different processes, which should each have a different distribution. The writer had suspicion of fitting this limited data to a distribution, but an attempt was made. The fitdistrplus library is used again, as in the case of Demand Distribution of Profilers. However, due to the limited data, it is difficult to make any conclusions about the distributions. In all three cases, either Cullen and Frey plot did not show a good fit, or the Empirical and Theoretical Distribution Plot shows that the theoretical and empirical data fit less than perfectly (see Figure 5-16). If more data points were collected, it will be possible to obtain more accurate distributions.
A further attempt was made to aggregate the replenishment time of all 19 shop orders. However, the Empirical and Theoretical plots did not show a good fit (see Figure 5-17). This led the writer to decide not fitting the data to any distribution, and instead to assume that the current replenishment time has a constant mean of 5.21 days.

Figure 5-16: Empirical and Theoretical Plots showing a bad fit, after fitting the Inspection data to a Negative Binomial Distribution

Figure 5-17: Empirical and Theoretical Plots showing a bad fit, after aggregating all 19 shop orders
Under the consolidation strategy, there will be no Duo-Location shorts. The replenishment time will include the lead time that a supplier needs to replenish the part, as well as the inspection time (if any). The May 26th to June 26th 2017 data is used again. This time, there are only 16 shop orders with recorded dates. The mean replenishment time increases to 5.75 days. This is understandable, because for the current replenishment time, the Duo-Location shorts are fulfilled by the Warehouse, which has a shorter lead time of only two days [5].

5.6.7. Truck Transfer

Assuming that the Profiler kits are transported in trucks with the current utilization rate of 53% (i.e. half truckload), the truck transfer is estimated to be 25.5 minutes, at the current speed of truck transfer.

Time Required to Transfer Half Truckload from Warehouse to Main Building

\[
\begin{align*}
\text{Time} & = \text{Open & Close Doors} + \text{Driver Disembarks & Embarks} + \text{Load 6 pallets} + \text{Drive} + \text{Open Doors} \\
& \quad + \text{Driver Disembarks} + \text{Unload 6 pallets} \\
& = 1\text{min} + 3\text{min} + 6 \times 1.5\text{min} + 4.5\text{min} + 0.5\text{min} + 1.5\text{min} + 6 \times 1\text{min} \\
& = 25.5\text{min}
\end{align*}
\]
5.6.8. Assembly & Testing

Using the build and test time data from the last 12 months on all Profilers, the average build time of the Profiler assemblies in Table 5-7 is found to be 12.24h.

Table 5-7: Assembly and Testing Time for Profilers

<table>
<thead>
<tr>
<th>Profiler Assembly</th>
<th>Average (h)</th>
<th>Std Dev (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E11349360</td>
<td>11.13</td>
<td>2.88</td>
</tr>
<tr>
<td>E11356600</td>
<td>12.00</td>
<td>0.00</td>
</tr>
<tr>
<td>E11356640</td>
<td>11.93</td>
<td>4.42</td>
</tr>
<tr>
<td>E11371790</td>
<td>13.78</td>
<td>4.01</td>
</tr>
<tr>
<td>E11426740</td>
<td>12.79</td>
<td>4.96</td>
</tr>
<tr>
<td>E11550420</td>
<td>9.83</td>
<td>2.43</td>
</tr>
<tr>
<td>E11641080</td>
<td>13.62</td>
<td>4.49</td>
</tr>
<tr>
<td>E11641090</td>
<td>14.31</td>
<td>4.23</td>
</tr>
<tr>
<td>E11641095</td>
<td>10.75</td>
<td>0.00</td>
</tr>
</tbody>
</table>
5.6.9. Failure Rate

There were 224 Profiler sub-assemblies built and tested between July 10th 2016 and July 11th 2017. During the building and testing process, 55 Profilers failed at a certain point. In total, there were 62 instances of failure on Profilers in the SMKT area during the same period. 95.2% of the replacement parts used to remedy the failure are stored in the SMKT, and 4.8% are stored in Warehouse. The actual time required to fulfil the Window Req of a part stored in the Warehouse is hard to obtain. Depending on whether a part is needed urgently, the course of action differs. If a part is needed urgently, there will be a designated runner who will personally go to the Warehouse to request, wait for, and pick up the part. If the part is not needed urgently, the request will be sent on via SAP. There is no record of the actual time taken to fulfill the Window Req. Using information from interviews with SMKT Profiler assemblers and production leads, it is deemed reasonable to assume that it takes 6 hours to fulfil a Window Req, roughly one-third of the total duration that the Warehouse operates in a day.

\[
\text{Time to replenish} = \frac{(0\text{min} \times 95.2\% \times 62 + 6h \times 4.8\% \times 62)}{62} = 0.29h
\]

Figure 5-18: Location of Window Req Items (Current SMKT)

The consolidation strategy will cause fewer parts to be stored in the SMKT. To mitigate the impact on cycle time, Zhang is proposing a list of the frequently Window Req-ed parts that could be stored in the SMKT [6]. Taking into account this new arrangement, the proportion of Profiler parts that could once be replenished directly by the SMKT drops from 95.2% to 53.2%.
Simulating a Bulk Queue Model on FlexSim, Zhang found that the average replenishment time is 1 hour per Window Req. This replenishment time refers to the time the Window Req is initiated till the time the replacement part reaches the SMKT. For a detailed explanation, please refer to Zhang’s thesis [6]. As a result, the replenishment time for a Profiler Window Req will increase from 0.29 hour to 0.47 hour.

\[
\text{Time to replenish} = \frac{(0\text{min} \times 53.2\% \times 62 + 1\text{h} \times 46.8\% \times 62)}{62} = 0.47\text{h}
\]

Figure 5-19: Location of Window Req Items (Consolidated Inventory)
5.6.10. Results on Cycle Time

Both FlexSim models were simulated for 40,000 virtual hours, or 1,667 virtual days. A statistics report is generated to give the average stay time, and the average content of every queue and every processor. The cycle time is found by:

\[
\text{Cycle Time} = \frac{\text{SUMPRODUCT(Average Stay Time, Average Content)}}{\text{Flowline Input}}
\]

It is found that cycle time per Profiler decreased by 11\% from 5.37 days to 4.84 days. This indicates that the factory has potential to increase its production output by adopting the consolidation strategy.

![Cycle Time Comparison](image)

Figure 5-20: Cycle Time Comparison using simulation data from FlexSim
The number of short Profiler kits decreased by 21% from 1,222 to 970.

Figure 5-21: Shortage Comparison using simulation data from FlexSim
5.6.11. Robustness Check

The simulation models were tested for robustness by changing the influential inputs of the model. From the Stay Time Calculation, it is possible to determine the queues and processor in which the Profilers will stay the longest, and are hence deemed most influential.

Table 5-8: Robustness Check Inputs and Results

<table>
<thead>
<tr>
<th>Case</th>
<th>Cycle Time (Consolidated)</th>
<th>Percentage Change wrt Baseline</th>
<th>WH Picking Rate</th>
<th>Replenishment Time</th>
<th>Truck Transfer Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.84 days</td>
<td>-</td>
<td>48min/kit</td>
<td>5.75 days</td>
<td>25.5min</td>
</tr>
<tr>
<td>2</td>
<td>4.95 days</td>
<td>2%</td>
<td>3.44h/kit</td>
<td>5.75 days</td>
<td>25.5min</td>
</tr>
<tr>
<td>3</td>
<td>4.91 days</td>
<td>1%</td>
<td>3.44h/kit</td>
<td>5.75 days</td>
<td>40.5min</td>
</tr>
<tr>
<td>4</td>
<td>5.08 days</td>
<td>5%</td>
<td>3.44h/kit</td>
<td>6 days</td>
<td>40.5min</td>
</tr>
<tr>
<td>5</td>
<td>5.96 days</td>
<td>23%</td>
<td>3.44h/kit</td>
<td>7 days</td>
<td>40.5min</td>
</tr>
<tr>
<td>6</td>
<td>5.13 days</td>
<td>6%</td>
<td>48min/kit</td>
<td>6.25 days</td>
<td>25.5min</td>
</tr>
<tr>
<td>7</td>
<td>5.27 days</td>
<td>9%</td>
<td>48min/kit</td>
<td>6.5 days</td>
<td>25.5min</td>
</tr>
<tr>
<td>8</td>
<td>5.37 days</td>
<td>11%</td>
<td>48min/kit</td>
<td>6.58 days</td>
<td>25.5min</td>
</tr>
</tbody>
</table>

Case 1 is used as the baseline.

In Case 2, the Picking Rate of the Warehouse is increased to from 0.5 minute/part to 2.17 minute/part, the average picking rate of replenishments from RK Rack, GL Rack, VLM. This is the worst case scenario. The cycle time increases, but by only 2%.

In Case 3, the Truck Transfer Time is increased from 25.5 minutes to 40.5 minutes. This increase of 15 minutes takes into account the worst case scenario that the truck has to unload 6 pallets, and load a full truckload of 12 pallets at the Warehouse. Strangely, the cycle time decreases from Case 2. The simulation was performed a second time, and the same result is obtained. Further calculation of the percentage of short revealed that in
Case 3, the percentage is 73.1%, but in Case 2, the percentage is 73.7%. This discrepancy is deemed to be a system bug.

In Cases 4 and 5, the replenishment time is increased from 5.75 days to 6 days and to 7 days, to explore the effects of variability on replenishment time. Once again, the replenishment time refers to the lead time that a supplier needs to replenish the part, as well as the inspection time (if any). An increase of 0.25 day is equivalent to 6 hours, and 74% of all parts are affected. Understandably, there is significant increase in cycle time.

In Cases 6, 7, and 8, the writer is trying to find the replenishment time that will lead to the current cycle time of 5.37 days. It is found that the replenishment time has to increase to 6.58 days. It is worth noting that even though the cycle time is the same, the output of the consolidated system is still higher than that of the current system by 2%.

5.6.12. Final Note

The FlexSim model is the writer's best estimate of the system, given the current availability of data. Judging from the robustness check, the models perform reasonably and logically. Extrapolating the simulation result for profiler, the consolidated system is likely to have a positive impact on both cycle time and shortage.
5.7. Financial Analysis

The FlexSim simulation gives a good sense of what could happen if the Profiler sub-assembly is picked at the Warehouse. In order to extrapolate the impact of the consolidation strategy to all SMKT sub-assemblies, a financial analysis is carried out.

The financial analysis is divided into three categories:

- Cost Savings
- Non-Recurring Cost
- Recurring Cost

5.7.1. Cost Savings (Eliminate repetitive tasks)

Under the inventory consolidation strategy, Varian will be picking kits directly at the Warehouse. There will be no need to pick, transfer and re-stock the SMKT inventory replenishments. If Varian is able to eliminate the repetitive tasks of Warehouse replenishment picks, and SMKT put-away (i.e. re-stocking), Varian will be able to enjoy substantial annual cost savings. The repetitive tasks are specified in more detail in Table 5-9.

Table 5-9: Details of Current Repetitive Tasks

<table>
<thead>
<tr>
<th>Location</th>
<th>Task</th>
<th>Duration</th>
<th>Daily Frequency</th>
<th>Time Saved/Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehouse</td>
<td>Pick Replenishment</td>
<td>2.4min/replenishment</td>
<td>200</td>
<td>8h</td>
</tr>
<tr>
<td>SMKT</td>
<td>Put-away</td>
<td>2min/replenishment</td>
<td>200</td>
<td>6.7h</td>
</tr>
</tbody>
</table>
Table 5-10: Financial Cost of Eliminating Repetitive Tasks

<table>
<thead>
<tr>
<th>Cost Savings from eliminating repetitive tasks</th>
<th>200 transfers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of transfer/day</td>
<td>200 transfers</td>
</tr>
<tr>
<td>Picking Time/Transfer</td>
<td>2.43 min/transfer</td>
</tr>
<tr>
<td>Putaway Time/Transfer</td>
<td>2 min/transfer</td>
</tr>
<tr>
<td>Time Spent on Transfers</td>
<td>886 min</td>
</tr>
<tr>
<td>Number of Workdays (exc weekend)</td>
<td>260 days</td>
</tr>
<tr>
<td>Hourly labor cost</td>
<td>$ 100</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$ 383,933</td>
</tr>
</tbody>
</table>

The hourly labor cost at Varian, after including worker benefits, is $100 per hour. If implemented, an estimated 14.7 hour will be saved every day. This will amount to 3,839 labor hours, or $383,933 saved per year (see Table 5-10).

However, it is worth noting that the picking rate at the SMKT and the Warehouse is different (see Table 5-11). This is mentioned in the Subsection 5.6.4. It is estimated that the picking rate at the SMKT is 20% faster than in the Warehouse. The difference of picking 30 kits will be: 24h-20h = 4h/day. This will lead to a cost increase of $104,000 (see Table 5-12).

Table 5-11: Details of SMKT and Warehouse Picking Time

<table>
<thead>
<tr>
<th>Location</th>
<th>Task</th>
<th>Duration</th>
<th>Daily Frequency</th>
<th>Time Saved/Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehouse</td>
<td>Pick Order</td>
<td>48min/kit</td>
<td>30</td>
<td>-24h</td>
</tr>
<tr>
<td>SMKT</td>
<td>Pick Order</td>
<td>40min/kit</td>
<td>30</td>
<td>20h</td>
</tr>
</tbody>
</table>

Table 5-12: Financial Cost of Longer Picking Time

<table>
<thead>
<tr>
<th>Cost Increase due to Procedural Changes</th>
<th>8 min/kit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra Time for Picking Kits at BL80</td>
<td></td>
</tr>
<tr>
<td>Number of Kits/Day</td>
<td>30 kit</td>
</tr>
<tr>
<td>Extra Time Spent Picking</td>
<td>240 min/day</td>
</tr>
<tr>
<td>Hourly Labor Cost</td>
<td>$100</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$104,000</td>
</tr>
</tbody>
</table>
Despite the longer picking time, there will still be a net 10.8 hours will be saved every day. This will amount to 2,799 labor hours, or $279,933 saved per year.
5.7.2. Cost Savings (Rework)

Additionally, material rework due to SMKT shortages will decrease. Currently, material shortage causes an average of 22 hours of rework per Tool. This shortage can be due to two reasons: late z-pick, or late SMKT sub-assembly. A sensitivity chart is created to explore the impact of this proportion on the net savings (see Table 5-13). For this analysis, the proportion of a short SMKT sub-assembly is assumed to be around 50%.

Out of all SMKT shorts, 50% of the shop orders are Duo-Location shorts (see Figure 5-22). This translates to 22h*50%*50% = 5.6h of rework labor hours per Tool. With Varian making 280 Tools per year, it will be able to save a total of 1,559 hours, or $155,875 by reducing Duo-Location shorts (see Table 5-14).

Figure 5-22: Proportion of Duo-Location Shorts vs Other Shorts
Table 5-13: Sensitivity Analysis of Proportion of SMKT Shortage resulting in RMat Rework

<table>
<thead>
<tr>
<th>Proportion of SMKT shortage resulting in RMat Rework</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsequent Net Savings (Per Annum)</td>
<td>$405,138</td>
<td>$436,313</td>
<td>$467,488</td>
<td>$498,663</td>
<td>$529,838</td>
</tr>
</tbody>
</table>

Table 5-14: Cost of Reducing Material Rework

<table>
<thead>
<tr>
<th>Cost Savings from reducing rmat rework</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Rmat Rework Time per tool (SMKT &amp; z-pick)</td>
<td>22 h</td>
</tr>
<tr>
<td>Proportion of shortage due SMKT</td>
<td>50%</td>
</tr>
<tr>
<td>Proportion of SMKT shortage due transfer, CO27 &amp; minmax</td>
<td>50%</td>
</tr>
<tr>
<td>Total Rework Time Saved</td>
<td>5.6 h</td>
</tr>
<tr>
<td>Hourly Rework Cost</td>
<td>$100</td>
</tr>
<tr>
<td>Production output</td>
<td>280 tools/year</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$155,875</td>
</tr>
</tbody>
</table>
5.7.3. Cost Savings (Labor Hours Spent Dealing with Shortages)

Another area of cost saving is from reducing time wasted dealing with shortages. From the Build Log, which contains most sub-assemblies built over the past year, and from the Coversheets collected between May 26th and June 26th, the average number of kits picked per business day is 30, assuming only weekdays are business days. This amounts to 7,800 kits picked per year. From the Coversheets data, 36% of all kits are picked to a short, of which 50% of the short kits are short because of Duo-Location shorts (see Figure 5-22). This amounts to 1,415 kits being picked to a short every year. There has been no time study done to measure the time wasted per kit due to shortage. But some of the tasks that needs to be done include updating the shortage board, printing and pasting the shortage tag, checking for the shortage parts every now and then, time spent at the Warehouse processing a single part for a cross-docking. An estimate of 0.5h/kit is used currently. At an hourly labor cost of $100, the cost savings will be $70,762 (see Table 5-15). A sensitivity analysis is done to analyze the impact of varying the time on the net savings (see Table 5-16).

Table 5-15: Financial Cost of Eliminating Labor Hours Spent Dealing with Shortages

<table>
<thead>
<tr>
<th>Number of kits picked per day</th>
<th>30 kits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of days where kits are picked</td>
<td>5 days/week</td>
</tr>
<tr>
<td>Total number of kits picked per year</td>
<td>7800 kits</td>
</tr>
<tr>
<td>Probability of a kit being short</td>
<td>36%</td>
</tr>
<tr>
<td>Probability that a short kit is short due to transfer, CO27 &amp; minmax</td>
<td>50%</td>
</tr>
<tr>
<td>Number of short kits due to transfer, CO27 &amp; minmax</td>
<td>1415 kits</td>
</tr>
<tr>
<td>Amount of time wasted on each shortage</td>
<td>0.5 h</td>
</tr>
<tr>
<td>Hourly Labor Cost</td>
<td>$100</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$70,762</td>
</tr>
</tbody>
</table>

Table 5-16: Sensitivity Analysis of Time Wasted per Kit

<table>
<thead>
<tr>
<th>Time Wasted Per Short Kit</th>
<th>10min</th>
<th>20min</th>
<th>30min</th>
<th>40min</th>
<th>50min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsequent Net Savings (Per Annum)</td>
<td>$420,314</td>
<td>$443,901</td>
<td>$467,488</td>
<td>$491,075</td>
<td>$502,869</td>
</tr>
</tbody>
</table>
5.7.4. Cost Savings (Facilities Cost)

Every short kit will take up an average of 9.8 ft$^2$ of floor space in the SMKT. Reducing the number of short kits in theory means that Varian can find alternative use of the floor space. It is difficult to find the opportunity cost for the floor space. As such, it is assumed that the opportunity costs is equivalent to the facilities cost associated with maintaining the floor space. The unit facility cost obtained from a Financial Officer in Varian is $30.31 per square feet/year. Combining this number with the duration at which the kits remain short (see Figure 5-23), it is possible to estimate the facilities cost savings from eliminating the short kits. This unit facility cost is very low, therefore, the savings is rather underwhelming. Each year, there will only be $1,285 saved in facilities cost by eliminating the short kits (see Table 5-17).

![Figure 5-23: Mean and Standard Deviation of Lead Time for Part Shortage](image-url)
Table 5-17: Financial Analysis for Cost Savings in Facilities Cost

<table>
<thead>
<tr>
<th>Cost Savings from eliminating shortage delay</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings from eliminating delay due to transfer short</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency of transfer short</td>
<td>396 kits/year</td>
<td></td>
</tr>
<tr>
<td>Mean delay due to transfer short</td>
<td>2.23 day</td>
<td></td>
</tr>
<tr>
<td>Savings from decrease in cycle time</td>
<td></td>
<td>30.31 per SF/year</td>
</tr>
<tr>
<td>Number of Floor Area per kit</td>
<td>9.8 SF</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td>719</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost Savings from eliminating CO27 delay</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of CO27 short</td>
<td>382 kits/year</td>
<td></td>
</tr>
<tr>
<td>Mean delay due to CO27 short</td>
<td>1.3 day</td>
<td></td>
</tr>
<tr>
<td>Savings from decrease in cycle time</td>
<td></td>
<td>30.31 per SF/year</td>
</tr>
<tr>
<td>Number of Floor Area per kit</td>
<td>9.8 SF</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td>404</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost Savings from eliminating Minmax delay</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of Minmax short</td>
<td>127 kits/year</td>
<td></td>
</tr>
<tr>
<td>Mean delay due to Minmax short</td>
<td>1.56 day</td>
<td></td>
</tr>
<tr>
<td>Savings from decrease in cycle time</td>
<td></td>
<td>30.31 per SF/year</td>
</tr>
<tr>
<td>Number of Floor Area per kit</td>
<td>9.8 SF</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td>162</td>
</tr>
</tbody>
</table>
5.7.5. Non-Recurring Cost

The main non-recurring cost is the moving fee. This moving cost estimate is obtained by assuming the move will take one external truck, and ten external movers working ten hours a day over a span of two days. The truck rental cost is assumed to be $200/day, and hourly labor cost to be $50/h. It is assumed that the move will have to take place at both the SMKT and the Warehouse. This is because Warehouse has to first make space for the SMKT parts by moving low demand and no demand parts from the Warehouse to the Secondary Warehouse to create space for the SMKT material, before the SMKT can move its inventory over the Warehouse. In total, the moving cost will be $20,800 (see Table 5-18).

Table 5-18: Financial Analysis of Moving Cost

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Rate of Truck Rental</td>
<td>$200</td>
</tr>
<tr>
<td>Hourly Labor Cost</td>
<td>$50</td>
</tr>
<tr>
<td>Number of Trucks</td>
<td>1</td>
</tr>
<tr>
<td>Number of Movers</td>
<td>10</td>
</tr>
<tr>
<td>Number of days</td>
<td>2</td>
</tr>
<tr>
<td>Number of hours per day</td>
<td>10</td>
</tr>
<tr>
<td>Frequency of moves</td>
<td>2</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$20,800</td>
</tr>
</tbody>
</table>
5.7.6. Recurring Cost

Under recurring cost, there are two main areas. The first area is the cost associated with longer SMKT Window Req. As stated in Subsection 5.6.9, most parts used to fulfil a Window Req are currently stored in the SMKT inventory area. Out of 760 parts that failed in the SMKT area between July 10th 2016 and July 11th 2017, 92.5% are stored in the SMKT, and 7.5% are stored in other locations, such as BL70, Warehouse, or it has to be replenished by the supplier. This means that 92.5% of the time the SMKT sub-assembler can get a replacement part almost immediately.

![Location of Window Req (Current SMKT)](image)

Under the consolidated strategy, it is no longer to case. The time to fulfill the Window Req will be longer. The estimated time to handle a Window Req include 10 minute of picking, 5 minute of trucking from the Warehouse to SMKT, 2.5 minute of loading and unloading. This will result in an additional 0.29 hour for an estimated 1,384parts/year. This amounts to $40,367 per year (see Table 5-19).
Table 5-19: Financial Analysis of Cost of Window Req

<table>
<thead>
<tr>
<th>Frequency of window req</th>
<th>1384 parts/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg increase in labor handling time per window req</td>
<td>0.29 h</td>
</tr>
<tr>
<td>Cost of increase in labor handling time</td>
<td>$100</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$40,367</td>
</tr>
</tbody>
</table>

The second is the cost increase due to longer picking time, which is covered in Subsection 5.7.1, and summarized in Table 5-20.

Table 5-20: Financial Analysis of Cost of Longer Picking Time

<table>
<thead>
<tr>
<th>Extra Time for Picking Kits at BL80</th>
<th>8 min/kit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Kits/Day</td>
<td>30 kit</td>
</tr>
<tr>
<td>Extra Time Spent Picking</td>
<td>240 min/day</td>
</tr>
<tr>
<td>Hourly Labor Cost</td>
<td>$100</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$104,000</td>
</tr>
</tbody>
</table>
5.8. Capacity Analysis (Storage Space)

The capacity of the Warehouse has to be enough to accommodate the parts from SMKT. Zhang measured the physical volume of the inventory on the SMKT shelves. It is estimated that by the end of the implementation, 4,573 ft$^3$ of inventory has to be transported over to the Warehouse.

The VLM is a favorable location to store the current SMKT inventory. The picking rate at VLMs is faster than that of GL Racks. Additionally, VLMs is calculated to save inventory space up to 85% as compared to conventional racks [13]. Zhang and the writer set out to find the number of VLMs required to store the current SMKT inventory.

![Figure 5-25: Dimension of a VLM](image)
Since there are typically three tall bays to one pod, this is equivalent to 3.25 VLM pods, and is understandably a sizeable volume. Through interviews with the Warehouse managers, the team understands that the Warehouse has taken initiative to create storage space in the Warehouse. There are currently two policies being implemented. First, the Warehouse is disposing of inventory that have no future demand, and can be written off (i.e. ENO parts). Second, it is shifting items with low demand from the Warehouse to a Secondary Warehouse. This prioritization initiative needs to continue. It will help to keep the warehousing space for the high demand items, and will make room for the SMKT inventory items.
6. Implementation Plan

6.1. Test the Recommendation

The first step should be to validate the recommendation. The recommended way to do that is through a time study, and a series of assessments over a statistically significant period of time. The assessments will be elaborated in detail in Subsection 6.1.3.

6.1.1. Choosing the Sub-Assembly

First, Varian should choose to focus on one sub-assembly, or a group of sub-assemblies. Criteria to consider when choosing ideal candidates include:

- High proportion of Transfer, CO27, and Minmax shorts
- Large impact in terms of UES delay, and by extension RMat Rework

Both of these criteria will allow Varian to quickly obtain enough data to carry out a statistically significant assessment of the recommendation.

By looking at the Coversheets data, there are two groups of sub-assemblies that stand out:

- In-Vacuum Profilers (see Appendix B for aggregated list)
- EPM Lens Assembly (see Appendix E for aggregated list)

Eliminating the Duo-Location shorts will only fix the shortage problem for 17% of the Profilers kits. This is because out of 24 In-Vacuum Profilers that were short, only four had issues solely attributable to Transfer, CO27, or Minmax. The other 20 In-Vacuum Profilers had Actual Shorts, Inspection, and Minmax VMI issues, on top of the three causes mentioned. The recommendation is likely to have only a moderate impact on the On-Time Delivery of Profilers.

On the other hand, out of the nine EPM Lens Assemblies that are short, 78% or seven kits are short due to Transfer alone. In the seven Transfer short kits, there are five kits were picked to a short in just two days: two on 24th May and three on 11th June 2017. The
The recommendation is likely to have a large impact on the On-Time Delivery measure for EPM Lens.

However, if one compares the data collected by Zhang for the UES Impact, the In-Vacuum Profilers will have a disproportionately large impact on UES delay. With each Profiler late for an average of 5.83 days to the UES Flowline, four short Profilers might have caused a total of 23.3 days of delay. In comparison, with an average of 1.77 days/EPM Lens, the EPM Lens could have caused a total of 12.4 days of delay on the UES.

Since EPM Lens has a high proportion of Duo-Location Shorts, and In-Vacuum Profilers have a large impact on UES delay, Varian can consider choosing both In-Vacuum Profilers, and EPM Len for this validation phase.

6.1.2. Preparation Work
In preparation for the validation process, it is advisable that three things be carried out before executing the recommendation:

- Make Warehouse conducive for picking SMKT kits
- Ensure that SMKT kits are prioritized
- Assign an experienced SMKT picker to Warehouse
- Decrease size of SMKT replenishments (for affected bins)

6.1.2.1. Making Warehouse Conducive for Picking
This can turn into a long term project, but basic steps should be done at this stage. Picking is a time-consuming process that is done throughout the day by many workers. The effort put in to improve productivity early on will pay back in the long run. This will be especially true if Varian wants to pick 30 SMKT kits/day at the Warehouse.

Currently, the average picking speed at the Warehouse is 4.3 times the picking speed at the SMKT. The main drag is the picking at the GL Racks, which is on average 10 times
slower than the SMKT. A few issues could have contributed to the slower picking speed at the GL Racks:

- The nature of picking is different. There are genuinely more items to pick and process per order at the Warehouse.
- Items are not properly de-bulked from their original boxes for picking. The picker has to untangle wires or open bags, in order to reach the items.
- Items are stored in higher racks than in the SMKT. The pickers have to climb up a ladder to pick the items.
- The picking lanes of GL Racks are only one trolley wide, and there are ladders in between every GL Rack (see Figure 6-1). This means that it is not conducive to push a trolley when picking items. As a result, after picking one type of line item, the picker has to return to his counter to process them.
- Location of item may change based on availability of storage space. Pickers have to re-memorize the locations.
- Picker is new, and unfamiliar with the location of the items.

These reasons are not definite. They are observations by the writer during a time study, and during interviews.

To increase the picking speed, and prepare for picking SMKT kits, a few methods could be considered:

- Facilitate communication and learning between SMKT pickers and GL Rack pickers for exchanging of best practices.
- De-bulk all parts neatly for easier picking.
- Move low-pick items to Secondary Warehouse, and dispose of items with no demand, and can be written off, so that high-pick SMKT parts can be assigned to the lower shelves of GL racks, and into VLMs for easier picking.
- Relocate the SMKT parts in RK racks to lower shelves of GL racks, and into VLMs for easier picking. This is in line with the recommendation in Toor’s thesis [14].
- Widen space between GL Racks to fit a trolley and a ladder side-by-side, so that the picker can push a trolley to pick and process parts on the spot.
- Fix locations of items, and guide new pickers to pick faster.
It must be noted that the writer does not intend for all of these suggestions to be carried out before the validation phase. He has also not carried out a SMKT kit picking time study at the Warehouse. However, when comparing the situation between the SMKT and the Warehouse, the writer deems that some of the suggestions will be helpful for the Warehouse.

According to the robustness check of the FlexSim simulation, the picking time is not the biggest contributor to cycle time. But from the financial viewpoint, it will be beneficial to Varian, if the picking time of SMKT kits at the Warehouse can be comparable to that of the SMKT.

Figure 6-1: Floor Plan of Warehouse
6.1.2.2. Ensure that SMKT kits are prioritized

Table 6-1 shows the current picking priority at the Warehouse. The release of SMKT kits should be placed at the same, or if not higher, priority than DFT replenishments. This is especially since the parts that are picked during DFT replenishments are used to replenish SMKT bins.

Table 6-1: Picking Priority at the Warehouse

<table>
<thead>
<tr>
<th>Priority</th>
<th>Reason of Pick</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Backlog</td>
</tr>
<tr>
<td>2</td>
<td>Sales Picks</td>
</tr>
<tr>
<td>3</td>
<td>DFT Replenishments</td>
</tr>
<tr>
<td>4</td>
<td>Machines</td>
</tr>
<tr>
<td>5</td>
<td>Transfers</td>
</tr>
<tr>
<td>6</td>
<td>Shop Orders</td>
</tr>
</tbody>
</table>

6.1.2.3. Assign an experienced SMKT picker to Warehouse

SMKT pickers are the most familiar with the best practices of picking SMKT kits. It will be beneficial for an experienced SMKT picker to the Warehouse to perform the picks in person, or to oversee the pick.

6.1.2.4. Decrease size of SMKT replenishments (for affected bins)

This is necessary, because once Varian begins picking kits at the Warehouse, a portion of the replenishments that are currently delivered to the SMKT inventory area will instead be needed at the Warehouse. As such, the size of SMKT replenishments has to be adjusted accordingly.

6.1.3. Validation

The validation can be done in six methods:

1) Time Study
2) On-Time Delivery Assessment

3) UES/MOD Delay Assessment

4) RMat Rework Assessment

5) Shortage Assessment

6) Financial Assessment

The purpose of the time study is to measure the cycle time of the shop order in the system. This will involve studying all the steps from picking a shop order to delivering it to the Flowline. The results of the time study can also be used to perform a financial assessment of the recommendation. A time study of the current system should be done, before attempting to validate the recommendation. This will allow for a basis of comparison when the time study of the recommendation is available. A point worth noting is that there is an additional step in the new process: the truck transfer step. Currently, it is a step external to the operation of the SMKT, but under the recommendation, truck transfer will be part of the new SMKT process. This may have to be taken into account when comparing the results of the time study with the previous results.

In addition to the time study, it is advisable for the SMKT Supervisor to continue tracking the On-Time Delivery of the kits, and the number of days of UES and MOD delay that the late SMKT kits cause. This will allow the company to analyze the impact of the recommendation.

The RMat Rework Assessment will measure the amount of rework hours spent dealing with material shortages. It is advisable that the cause of RMat Rework be identified on the Flowline, in order to assess the severity of the SMKT sub-assembly late delivery problem.

The financial assessment will involve tracking the actual financial cost/benefit of the recommendation. From Section 5.7, the bulk of the cost savings will come from savings in labor hours from eliminating repetitive tasks and reducing RMat rework. As mentioned earlier, the result from the time study can be used as inputs for the financial assessment.
It is necessary to compare the actual cost of this recommendation with the projections in this thesis.

6.1.4. Duration of Validation Phase

As aforementioned, the duration of the validation phase should be statistically significant. To the writer, if only the EPM Lens Assembly is used for this validation, the results may only be statistically significant after three weeks to a month. This is considering that a large number of shortages usually occur in short interval of time.

Additionally, it is important to consider that the picking environments are different. The SMKT is conducive for pushing trolleys along the aisles, and picking as one proceeds. The Warehouse is built for a different variety of picking. In the GL Racks for instance, pickers pick each type of line item, and returns to their counters to process the group of items.

When picking of kits happen at the Warehouse, it is important to allow the picker to familiarize himself or herself with the locations of the items in the shop order, and perform the picking long enough to allow the picking rate to reach a steady state.
6.2. Implement the Recommendation

Once the validation results are deemed to be satisfactory to Varian, it can consider a controlled expansion of the recommendation to more SMKT kits. Time studies, and the series of assessments has to be firmly put in place to continue tracking the progress of the recommendation.

As more SMKT kits are picked at the Warehouse, storage space at the Warehouse will be an issue. The prioritization initiative that is already underway in the Warehouse needs to continue. Perhaps more stringent criteria have to be put in place to ensure only the highest pick parts remain at the Warehouse. The Secondary Warehouse will also have to be better staffed to accommodate for the higher number of line items and picks, once the low-pick items are moved over.

Once 50% to 75% of all SMKT kits are picked at the Warehouse, Varian can stop SMKT replenishments for the Non-Minmax items, and only focus on replenishing only the 65 Window Reqs and the Minmax items at the Main Building. Please note that the 50% to 75% figure is not based on any mathematical model; it is merely a placeholder for the actual confidence level that Varian feels regarding implementing the recommendation on a large scale. For detailed explanation about replenishment strategies of the Window Reqs, refer to Zhang’s thesis [6]. With regards to the actual moving process, Varian can consider contracting a moving company to move remaining SMKT material back to Warehouse. The financial cost of the move of inventory from SMKT to Warehouse is estimated in the Financial Analysis to be the range of $10,400. The move will ideally be on a weekend to minimize disruption to production, and for worker safety.
7. Conclusion & Future Work

In face of rising demand in 2018 and 2019, Varian will benefit from resolving the SMKT On-Time Delivery issue swiftly and decisively. The writer expects the use of the consolidated inventory strategy to definitively reduce the Duo-Location Shorts, and greatly alleviate SMKT’s On-Time Delivery problem. The inventory consolidation strategy will help eliminate 64% of all SMKT shortages, provide the company with 3,000 ft² of production floor space for capacity expansion, and save Varian $467,488 per annum in labor hours and rent. More importantly, the consolidation strategy will put Varian in a more productive and competitive position to capitalize on the fast-growing semiconductor industry.

That being said, although the inventory consolidation strategy will help to reduce the instances of SMKT shortage by 64%, a kit can have both GL and Real shortages. In fact, a short sub-assembly kit has an average of 1.8 shorts. In order to completely eradicate the SMKT kit shortage problem, and improve SMKT On-Time Delivery, it is recommended that Varian look into resolving the Real shorts as well.
8. References

Appendix A

Coversheet Sample

---

**SMKT KIT COVERSHEET**

**Order Type:** Tool/Customers/GS  
subassembly number * qty

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>QTY</th>
<th>DESCRIPTION</th>
<th>SMKT LOCATION</th>
<th>P.O. DUE</th>
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</thead>
<tbody>
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**KNOWN SHORTAGES**

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>QTY</th>
<th>DESCRIPTION</th>
<th>SMKT LOCATION</th>
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</thead>
<tbody>
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**UNKNOWN SHORTAGES**

<table>
<thead>
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<th>PART NUMBER</th>
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</thead>
<tbody>
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**GL PARTS**

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<th>DESCRIPTION</th>
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</thead>
<tbody>
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</tr>
</tbody>
</table>

Date + time placed on rack (after pick): / /  
Time: AM PM (circle one)

Started by:  
Date: / /  
Time: AM PM (circle one)

Continued by:  
Continued by:  
Completed by:  
Date: / /  
Time: AM PM (circle one)
Appendix B

List of Profilers Used in Simulation

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<thead>
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<th>IN-VAC PROFILERS</th>
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<table>
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<td></td>
<td>E11128550</td>
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<tr>
<td></td>
<td>E11349360</td>
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</table>

Source: STD Labor Hours 07.17.17
Appendix C

Annotated R Code to Fit Data to Distributions

%load library and data file
library(fitdistrplus)
csv.load(C:/Files/demanddata)

%Generates Cullen and Frey Graph to fit data to distribution
descdist(demanddata, discrete=TRUE)

%Assuming that the Cullen and Frey Graph has fitted the data to a negative binomial distribution
fit.negbin -> fitdistr(demanddata, “nbinom”)

%Plot Theoretical and Empirical Distributions
plot(fit.negbin)
Appendix D

Value Stream Map (Warehouse)
Value Stream Map (SMKT)
Appendix E

EPM Lens

<table>
<thead>
<tr>
<th>Assy Number</th>
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<tbody>
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<td>E11629790</td>
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<td>E11616510</td>
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