Implementation of RFID in a Low Volume High Flexibility Assembly Plant: Process Redesign

by

Yulei Sun
B.S. in Automotive Engineering,
Tsinghua University, China, 2009

Submitted to the Department of Mechanical Engineering
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Abstract

This thesis focuses on the operational improvements in a semiconductor equipment manufacturing company (Varian Semiconductor Equipment Associates). The company faces challenges of highly fluctuating demand as well as complex and highly customized assembly, which lead to problems such as lead time control and components tracking at multiple manufacturing stages. The goal of the project is to propose an efficient assembly system with the ability of parts checking and tracking.

Radio Frequency Identity (RFID) technology is introduced as the core method to treat the problems, in such a way that RFID tagged parts can be sensed automatically by antennas and identified by the system. In order to implement the system and maximize the benefits, redesign of the manufacturing process is proposed and discussed as the main results of this thesis. To achieve the goal, the current operations are carefully captured and analyzed; the RFID technology is briefly described as the basis of designing new procedures; the lean principles are introduced to refine the processes; and the simulation is applied to evaluate the changes between the old system and the new system.

The solutions include three phases: 1) RFID for miscellaneous parts checking, 2) RFID for module parts tracking, 3) RFID for parts tracking in the flow line, respectively corresponding to the three problems:1) Inefficient operation of miscellaneous parts, 2) fraudulent claims and warranty costs, and 3) deficient tracking ability. The analysis of benefits and the simulation results suggests a potential reduction of costs. A new material flow map and new procedures of certain stages are proposed. Finally, the two pilots are developed as stepping stones to formal implementation of the RFID system in VSEA.

Thesis Supervisor: David E. Hardt
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1. Introduction

1.1 Project motivation

High complexity manufacturing plants with a broad production mix at low volumes are highly dependent on human labor. Typically, such facilities are viewed as unsuitable for task automation due the high degree of product customizability required. However, recent technology advances have made available solutions that enable efficient modification of processes to reduce production time by eliminating repetitive tasks.

As a manufacturer of high precision machines, Varian Semiconductor Equipment Associates (VSEA) must maintain strict quality requirements and offer its customer high flexibility, while consistently meeting delivery deadlines. As such, the company's operations are highly labor intensive and time consuming, resulting in long lead times and high production costs.

The project discussed in this thesis was undertaken by a team of three students enrolled in the Master of Engineering in Manufacturing program at MIT and was sponsored by VSEA. Its objective is to assess the viability and technical feasibility of the implementation of an RFID-enabled system to trace parts throughout VSEA's factory, eliminating the need for labor-intensive inspections.

1.2 Presentation of the Company

1.2.1 Overview

Varian Semiconductor Equipment Associates, Inc. (VSEA) specializes in the design, manufacture, and servicing of ion implanters, a type of semiconductor processing equipment used in the fabrication of integrated circuits. Founded in 1971 in Peabody, MA as Extrion Corporation and acquired by Varian Associates in 1975, it was then spun off in 1999 as an independent company based in Gloucester, MA. Over the past 30 years, VSEA has managed to maintain a strong position as a supplier of ion implanters, adapting its product line to handle gradually increasing wafer sizes from the 1 in standard in 1980 to the current 300mm wafers. [1]

1.2.2 Customers

VSEA's customers are semi-conductor manufacturers such as Intel, IBM or Samsung. VSEA is established worldwide and has a strong presence on the Asian market, with customers from Asia accounting for over three quarters of the company's revenue. The very high upfront investments (hundreds of millions of dollars) required to start a semi conductor production facility constitute a significant barrier to entry into the market, and therefore the few existing players have remained essentially the same over the years. As such, these customers have accumulated considerable buyer influence, enabling them to demand and obtain high customization and low lead time. VSEA has attempted to standardize some of the modules on the high current machine (e.g. beamline), but still often finds itself obligated to comply with customer wishes in terms of selects and options. The power of buyers in the semi-conductor industry, leading to low standardization and human-intensive production, is therefore one of the major causes for inefficiencies in the operations of VSEA and semi-conductor equipment manufacturers in general.

1.2.3 Market Position

Over the past 8-10 years, VSEA has actively endeavored to widen the gap with its competition in the ion implanter market. It has grown from about 30% to over 70% of market share, and holds the top position as a manufacturer for all 4 lines of products it provides (High Current, Medium Current, High Energy and PLAD). In the High Current implanter market, VSEA has steadily broadened its customer base, supplying most of the top 20 (including the top 3) semi-conductor companies as ranked by the size of their capital expenditures.

1.2.4 Product Offerings

Having become the most prevalent method for high-productivity doping of silicon wafers, ion implantation is a critical processing step of semiconductor device fabrication. VSEA specializes in the production of single-wafer, high productivity ion implanters, and offers a full suite of high current (HC), medium current (MC) and high energy (HE) models based on the common VIISta Platform, which includes a dual-magnet ribbon beam architecture, the VSEA's proprietary Varian Control System (VCS) and Varian Positioning System (VPS), as well as a single-wafer end station. Figure 1 shows the components of the VIISTA platform. [2]

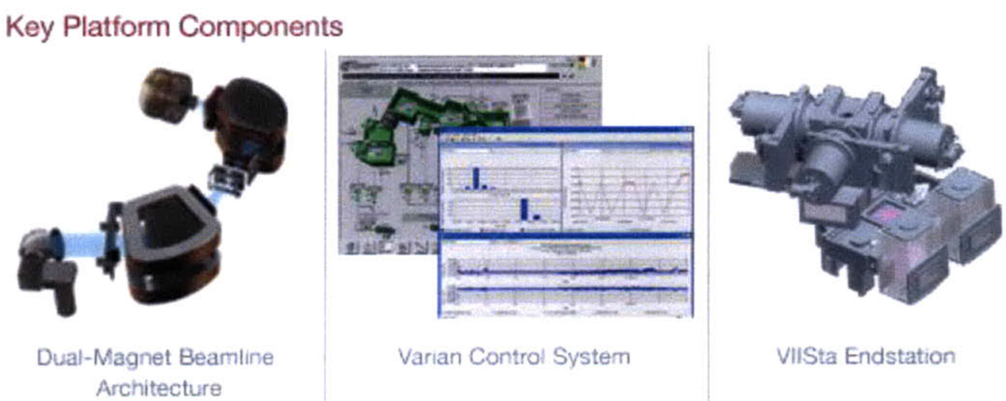

Figure 1: Components of the VIISTA platform

The main differences between these three product categories are the dose of ion used and the energy supplied for implantation. HC machines have higher doses which translates into higher ion concentrations on the wafer surface, while the MC and HE machines have higher energy, resulting in increased implantation depth. There are different types of machines under each category, designed to fit the particular 'recipes' produced at the customer's fab. They are shown below.

High Current (HC)	Medium Current (MC)	High Energy (HE)
VIISta HCS	VIISta 810XP	VIISta 3000XP
VIISta HCP	VIISta 810XEr	
VIISta HC	VIISta 900XP	

VSEA is also in the process of introducing its PLAD (Plasma Doping) line of implanters to accommodate ultra-high dose applications.

1.3 Semiconductor Equipment Industry

The semiconductor industry where VSEA operates is a highly competitive and fast-paced one which represents a market of over $260 billion. Despite an average annual growth of 13% over the past 20 years, the market has also suffered from above-average market volatility, subjecting it to dramatic cyclical changes. [3]

A semiconductor fabrication plant can cost up to $4 billion to build, and consists of hundreds of high-precision equipment items, such as steppers, etching machines and ion implanters, which can cost upwards of $4 million each. [4]

In order to accommodate the fast pace of technological innovation in the field of semiconductor manufacturing, suppliers such as VSEA must constantly improve the performance of their devices while keeping prices constant. This leads to concern over operational efficiency and, in the case of VSEA, results in a push for lean production.

Having achieved significant reductions in lead time through the introduction of SmartShip (see Section 2.2) and other initiatives, VSEA shifted its focus to improving shipping operations. Accurate and on-time shipping is crucial to VSEA and its customers, as any delay may result in a halt of semiconductor fabrication at the client's site, potentially resulting in hundreds of thousands of dollars in lost revenue. As such, tracking of outgoing shipments is required, while total shipping time must be minimized.

1.4 General RFID Introduction

After in-depth analysis of VSEA's current operations (which is detailed in Section 2 below), it was decided that the improvement that would benefit shipping operations and overall lead time most was the implementation of RFID tracking at VSEA. The remainder of this thesis will assess the technical feasibility of RFID for both high-level (large components and modules) and low-level (individual items or small sets of items) tracking of parts. It will also make concrete proposals about modifications to current operations that would make RFID implementation most effective.

RFID technology, which is described in details in section 4, allows for unique identification of products or parts without requiring line-of-sight reading, thus increasing depth of serialization and reducing the time spent counting inventory through simultaneous reading of several tags. [5]

In recent years, and following mandates by Wal-Mart and the US Department of Defense, RFID tagging for pallet tracking and high-level inventory management has become commonplace. [6] The technology is versatile, and can be adapted to numerous other applications, yet caution must be exercised in implementing it, as it is still incipient in some regards. Section 4 will discuss some of the specific challenges expected for our application in VSEA's industrial environment.

1.5 Thesis Structure

In the next section, VSEA's operations are described in detail. The problem at hand is then clearly defined in section 3, both qualitatively and quantitatively, and the scope of the work narrowed. Review of theoretical background and previous work is summarized in section 4, while the methodology followed to study the problem is introduced in section 5. The results obtained are shown and discussed in section 6, 7, 8 with the appropriate recommendations. Section 9 concludes the entire project and suggests future work.

2. Description of Operations at VSEA

2.1 Company-Specific Language

VSEA employees use company jargon to describe certain processes, internal transactions and record-keeping forms. A brief overview is presented here.

2.1.1 Types of Orders

A *Machine Order* (or *Tool Order*) is the original order placed by VSEA's customer. These orders are collected by sales representatives and include different selects and options based on the customer's specific requirements. The machine order will include information about the agreed upon price, shipping date, terms and conditions.

A *Production Build Order* (PBO) is an expansion of a machine order. A PBO is a list of about a hundred *line items* representing all the assemblies (represented by their part codes) of the particular configuration ordered by the customer. A PBO is a dynamic document and can change upon customer request. In an effort to limit the disruptions caused by last minute requests, VSEA has instated a 10-day 'freeze' period prior to shipping, during which changes can no longer be made to the PBO.

A *Sales Order* is the order of spare or replacement parts by the customer for maintenance purposes. Internal orders to replenish 'material banks' (located all over the world to provide parts and support to customers) are also considered sales orders. Some sales orders may be assigned higher priority than others for various reasons (an *Emergency Order* or EMO represents the highest priority items).

A *Shop Order* (or *Work Order*) is issued to production workers to fulfill a single assembly or part collection task or perform machine testing. Shop orders have a multi-level hierarchical structure. For instance, at the highest level, a single shop order can be issued by a production manager for the assembly of the entire beamline module. At the lower levels, shop orders will be issued for each subassembly under the module shop order.

An *Engineering Change Order* (ECO) is used to document a design change to the current machine architecture. There are various reasons for having ECOs, including machine upgrade, bad part performance at customer site or discontinuation of the part by suppliers. Typically an ECO goes through a process of design, approval, testing and documentation before the change is applied to the machine.

2.1.2 Kit Codes

Kit Codes are used in all aspects of VSEA's current operations. Originally, kit codes were meant to represent the breakdown of the machine into its multiple components and organize the production sequentially. For instance, 1LA stands for end station kit, 4V stands for beamline and terminal kit and AV stands for final assembly kit. It is interesting to note that under a single *kit code*, there may be several *kits* (coherent collections of parts and sub-assemblies serving a common function, or included in the same higher level subassembly), each containing a mix of parts and subassemblies purchased from suppliers and subassemblies produced in house. Production supervisors used to pull parts from stock by kit codes in a sequence, such as 1LA1, 1LA2 and then 1LA3, (Figure 2, 1LA refers to kit codes pertaining to the end station module), but over time, new kit codes were created and existing ones were modified without regard to the original function, leading to gradual loss of the sequential order.

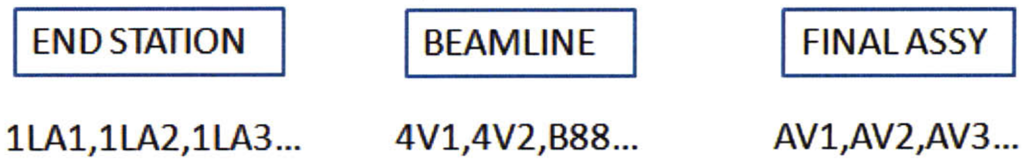

Figure 2: General structure of the kit codes

Currently, kit codes are all at the same level (no hierarchy) and based on a rough division of parts at the module level. This means production managers and engineers are forced to modify the contents of each kit code for each new machine order, depending on the desired configuration. The kit codes are then pulled onto the flow line by production coordinators and material handlers in a custom sequence dependent on previous experience.

2.1.3 Bill of Materials

A *Bill of materials* (BOM) is a hierarchical list of all the components in a machine. A BOM goes from the entire machine down to the modules, major components, smaller subassemblies and single parts. It also keeps track of the quantities of each component that are required for the final assembly of the machine given the particular configuration ordered.

2.2 Manufacturing Operations

'Manufacturing' at VSEA designates all assembly and testing operations. Assembly operations include production of subassemblies and assembly of modules whereas testing occurs at module-level or on the entire machine. The machines tested as a whole are known as *Full Build* orders, as opposed to *SmartShip* orders, which undergo more extensive module testing but bypass the final assembly and complete machine testing stage, thus reducing production time by about 100 hours. Currently 50% of production consists of SmartShip orders, with a target of 80% by 2012.

VSEA outsources all its parts from a large number of third-party suppliers. The company also outsources subassemblies that do not contain core technology and cannot be assembled in house at a lower cost.

The factory is divided into different areas. All the assembly and testing is done in the main building in which there are four main functional areas:

- The *Supermarket* (SMKT) and the *source room* are the areas where subassemblies are produced. Parts inventory for the subassemblies are kept there.
- The *Flow Line* area is used for module assembly and testing
- The *Clean Room* is used for machine testing on full build orders, as well as for teardown tasks requiring a sterile environment.
- The remaining area is dedicated to shipping operations and includes an air shower area, as well as a packaging area where modules and parts are put into crates and loaded onto shipping trucks.

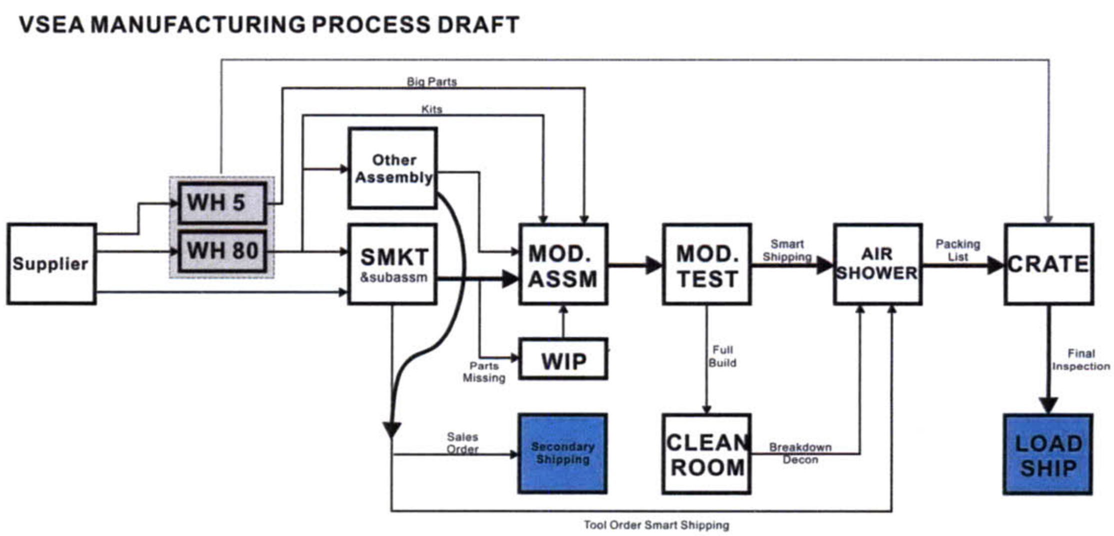

Figure 3: Flow of parts through VSEA's facility

With reference to Figure 3 above, the main operations at VSEA will be described in details in the rest of this section.

2.2.1 Warehouses

There are two warehouses at VSEA: WH5 and WH80.

WH5 is mostly used to stock big parts such as the machine enclosure or the end station. Parts from WH5 will usually be sent to the main building's flow line and clean room (in the case of a full build order), or straight to shipping (for SmartShip orders).

WH80 is the main warehouse, accounting for parts supply in subassembly and flow line. Figure 4 below shows the general flow of parts within: parts from suppliers are delivered in the receiving area, and shipment receipt is confirmed into the SAP management system. The received parts may be inspected, then proceed to the 'sorting desk', where order accuracy is checked. The parts are then shelved in the stockroom. Upon receipt of a pull order (from the flow line, supermarket, kit room or any other internal department) or a sales order (from parts banks or directly from customers), a 'shopping list' is generated, and warehouse workers fulfill orders by picking the parts from the shelves.

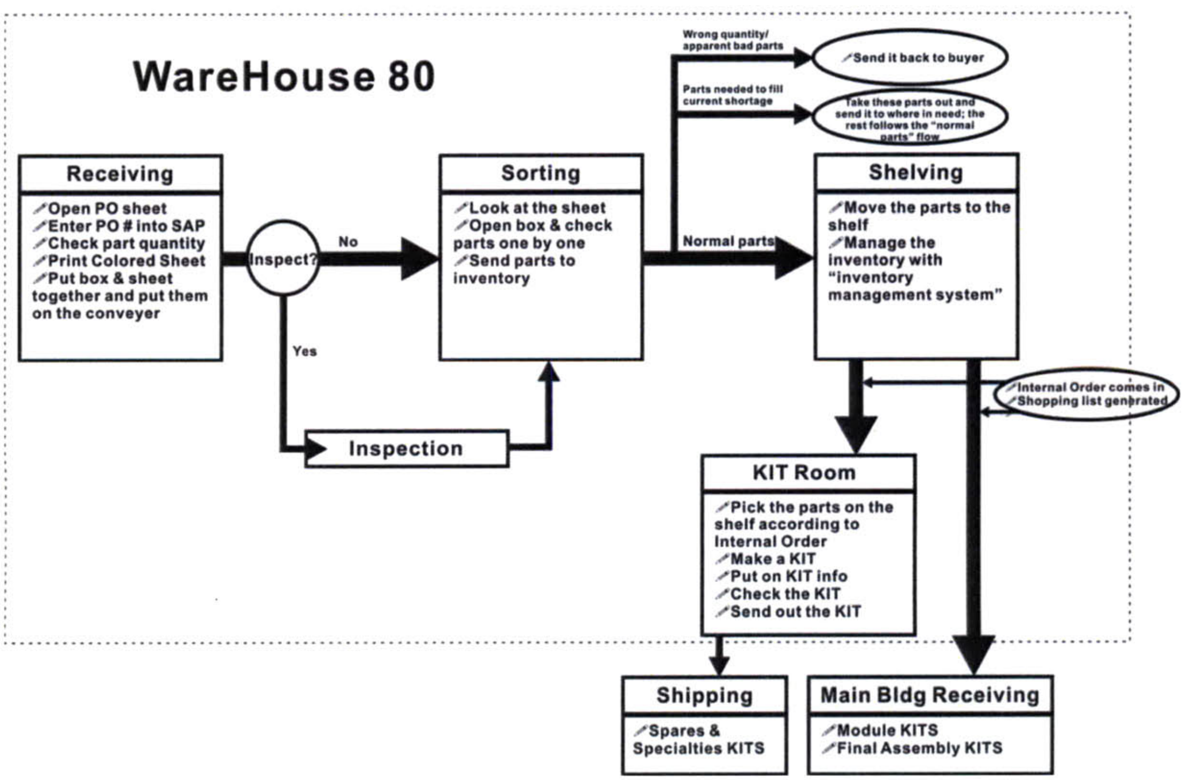

Figure 4: Flow of parts inside the warehouse

2.2.2 Kit Room operations

The 'Kit Room' is an area of the warehouse that essentially acts as an independent 'assembly' area, in that parts are pulled from the main warehouse stock room, and assembled into 'kits' (put in bins and bags and sent to different locations). The kit room mainly handles machine orders and sales orders, but may also ship kits to the flow line and clean room.

2.2.3 Main Building receiving

The main building receiving area serves as a parts distribution center. Its main function is to dispatch parts to the different areas within the main building.

In general, the receiving area receives parts from three main sources:

- The warehouse WH80 (daily truck delivery).
- Main suppliers. Some of the suppliers will send their parts directly to the receiving area instead of the warehouse. The parts are generally delivered by national freight carriers, such as UPS or DHL.
- Local suppliers. Some local vendors will deliver parts directly throughout the day.

Upon reception of a shipment, several tasks must be executed at the receiving area. Similar to the receiving procedure in the warehouse (section 2.2.1), shipment content is inspected and purchase order information is entered into the SAP management system, updating the part's status and location. Around 90% of the parts which are packed in cardboard boxes then need to be de-trashed before being transferred to the assembly line on carts and pallets. There is a 3 to 5 hour lag between when the parts are marked as received and when they actually reach their destination within the main building.

In order to relieve receiving area workers from the burden of de-trashing all parts, some local suppliers have been asked to deliver their parts directly in clear plastic bins.

Some functional but obsolete parts (or parts already available in surplus and occupying the limited inventory space of the main building) produced in the SMKT or in the source room are sent back to the warehouse for storage (*Credit to Order*). Also, parts requiring inspection will often be sent back to the inspection area at the main warehouse. Finally, the receiving area also handles so-called "offline orders", delivered directly to engineers for test or research.

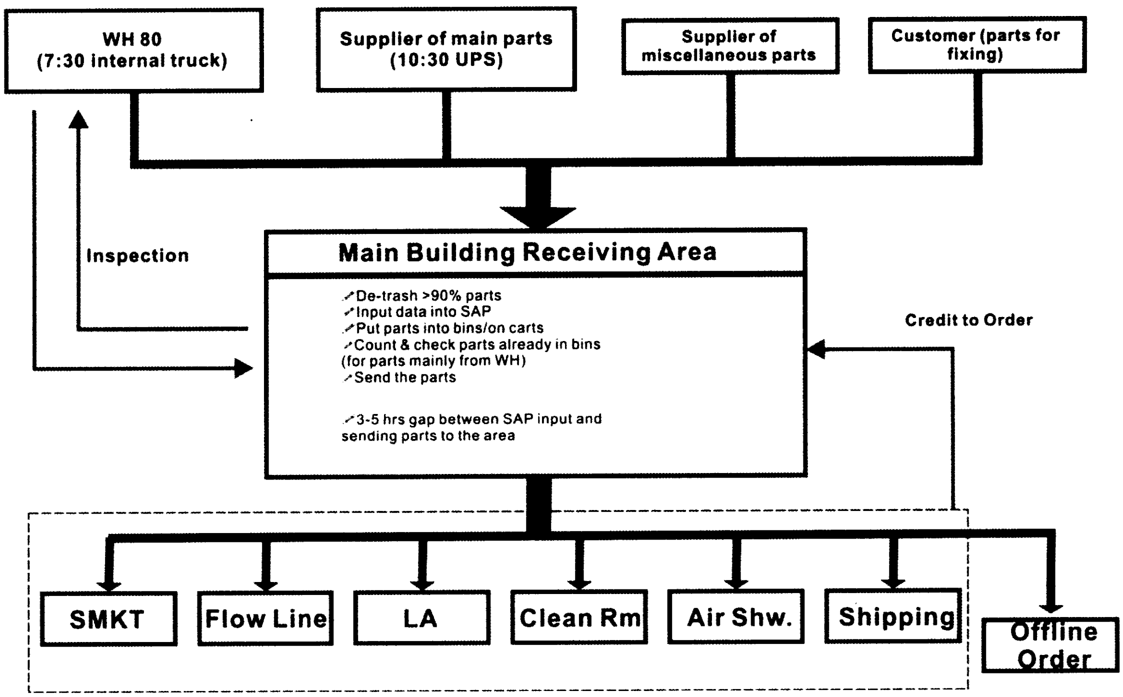

Figure 5: Flow of parts in Main Building Receiving

2.2.4 Supermarket and Source Room

There are two areas for subassembly: the 'source room' and supermarket (SMKT). Workers in these two areas produce the subassemblies that feed module assembly on the flow line, as well as those which are shipped directly as spares or replacement parts.

Both areas also keep their inventory at hand and use one of several inventory management systems:

- 15% of the SMKT inventory is controlled by Kanban. In VSEA's implementation, all parts controlled by Kanban are placed in two identical bins, and workers are directed to deplete the inventory from the first bin before using the second. A Kanban ticket is given to the material handler once the first bin is empty, triggering replenishment of that part's inventory.

- Some parts inventory are designated as Vendor Managed Inventory, which means suppliers are responsible for ensuring enough parts are present.
- "Point of Use" parts have their inventory managed by the MRP system, and can be used by assemblers without restrictions.
- A transaction record is needed for the use of high value parts.

In addition to regular orders, SMKT produces subassemblies into a Kanban-managed buffer called the "Golden Square" where a limited inventory of about 20 common subassemblies is kept for use as-needed.

2.2.5 Flow Line

The flow line serves two functions: module assembly and module testing. Flow line assemblers pull parts from the subassembly areas (Section 2.2.3), warehouse (2.2.1) and suppliers (through the receiving area – 2.2.4). Some parts are also delivered by the suppliers directly to the flow line floor. Extensive module testing (e.g. wafer cycling, leak testing of the gas box or electronics testing) is done on the flow line for SmartShip machine orders, whereas Full Build orders only undergo cursory testing at the flow line, most critical tests being conducted in the clean room on the complete machine (the distinction between SmartShip and Full Build orders was introduced at the beginning of section 2.2).

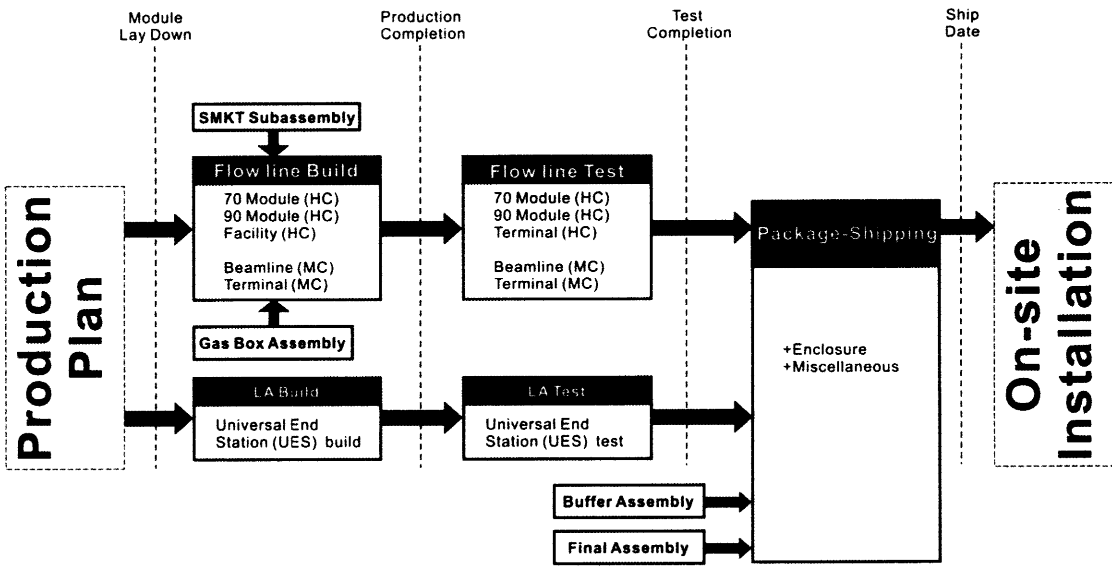

Figure 6: Flow of parts in Flow Line

2.2.6 Clean Room

Parts flow into the clean room for complete assembly and testing of the entire machine (Full Build orders). While modules from MC machines can be mounted on a slave enclosure, HC machines must go through the entire final assembly steps. Other slave parts, such as rough pumps, are used for testing. After testing, machines are taken apart to module level and sent to air shower for teardown.

2.2.7 Air Shower

Most parts, including modules, sub-assemblies and miscellaneous parts pass through the air shower before shipping. In this area, modules are torn down (partially), drained, decontaminated, cleaned and bubble wrapped, while miscellaneous parts typically just pass through the air shower and get wrapped. Air shower workers are also responsible for final inspection of the components of the outgoing modules.

2.2.8 Shipping Area

All outgoing parts are collected at the shipping area for final inspection, packaging and crating. The main modules, after teardown and inspection at the air shower, are placed directly into shipping crates. On the other hand, miscellaneous parts originating from the warehouse, clean room, flow line and subassembly area often require extra work, such as de-trashing, re-wrapping and extra assembly. This is particularly true for SmartShip orders, whereby all final assembly material must be processed by shipping worker.

The shipping area and the air shower have close relationship with each other, and together compose the entire packing-shipping process, the task breakdown of which, along with the reason each task is performed, are shown in Table 1.

Table 1: Tasks of packing-shipping process

Area	Task	Reason
Air Shower	Module tear down (partial)	Facilitates shipping (crate configuration)
	Module parts drained, decontaminated, cleaned and bubble wrapped	Regulatory requirement
	Module checking and general inspection	Basic quality requirement
	Extra-wrapping (partial)	Regulation requirement (for parts directly from warehouse)
	Extra-assembly (partial)	Customer requirement
Shipping Area	Packing list generation	To sign out parts during crating For parts checking at customer site
	Parts received from several upstream processes	Parts that don't require further work go directly to shipping
	De-trash (partial)	Parts arriving from the warehouse need to be taken out of packing materials to avoid contamination
	Extra-wrapping (partial)	Safety requirement for fragile parts
	Part 'check-out'	Guarantee the correct parts are shipped

	- Take the parts out of the WH bins -Count and check the parts -Put the parts into shipping bins -Sign out the packing list	Shipping process use its own new and clean bins which customers require Configure the bins/crates for easy installation Match the physical parts with the document
	Crating	Use crates for shipping
	Load crates on trucks	

3. Problem Statement

This section describes current problems within the manufacturing operations are identifies potential areas of improvement. Key factors considered include lead time reduction, waste elimination, and direct labor cost reduction. Thorough investigation of the internal parts flow directed the focus of this research towards three main issues:

1 – Inefficient operation of miscellaneous parts

2 – Fraudulent Claims and Warranty Costs

3 – Deficient tracking ability

3.1 Inefficient operation of miscellaneous parts

Parts move through VSEA's manufacturing facility follow one of the two distinct flows:

1. The *Module flow* consists of parts and subassemblies that will be assembled into large modules and shipped as a part of the assembled module.
2. The *Miscellaneous parts flow*, accounting for about 10% of the parts shipped out, consists of all the parts that will be shipped separately from the module (install kits, spares and replacement parts)

While the operation of Module flow has been the object of much attention in recent years and has been thoroughly refined, the operation of miscellaneous parts flow suffers from inconsistencies and labor intensive, resulting in efficiency losses and lead time increases. The latter will be described in this section.

3.1.1 Inconsistency of miscellaneous part flow

Miscellaneous parts for the **Medium Current** machines are delivered directly to the shipping area. With reference to the diagram below, the flow of parts is as follows:

1- Parts are delivered from the warehouse to the packaging area in a truck containing cages (2-3 bins, the rest is loose parts)
2- 50% of parts need to get de-trashed, the rest goes to steps 3, 4 or 5 directly
3- About 10% parts need to get wrapped, this happens in the air shower
4- About 5% of parts require extra assembly
5- Parts are put in bins
6- Parts and bins are crated then shipped out

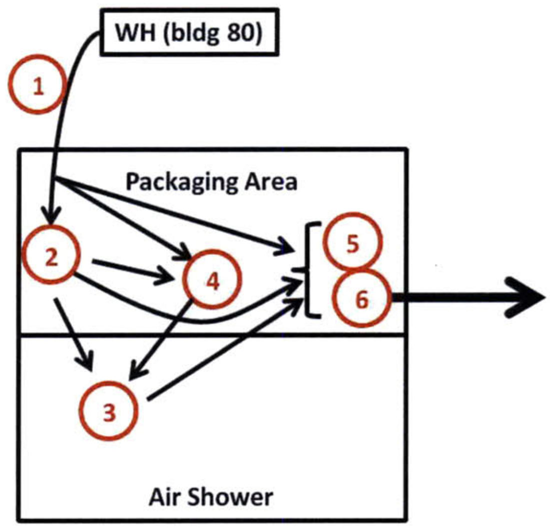

Figure 7: Flow of miscellaneous parts for the Medium Current SmartShip orders

The steps are identical for the **High Current** machines, except they are carried out in different areas, as shown in the diagram below.

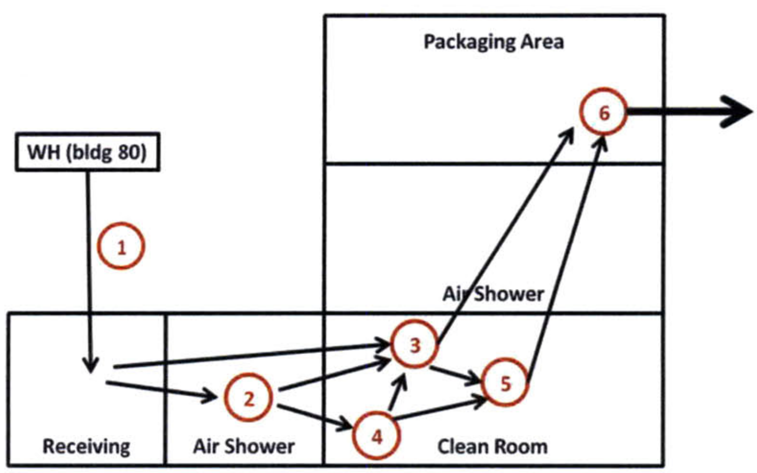

Figure 8: Flow of miscellaneous parts for the High Current SmartShip orders

The disadvantages come out as: 1) resources such as tools and equipment are dispersive, system losing utilization; 2) people in each area have multiple work, and fail to be dedicated to certain jobs, system losing efficiency; 3) complex flow causes confusion, being hard to track; 4) complex flow tends to hide the problems such as high inventory, low utilization and other indirect loss.

3.1.2 Complexity of operation at shipping area

As is indicated in Chapter 2 (2.2.8), much work beyond simple packaging and shipping are taking place in the shipping area, where the part flow is complicated.

First, the shipping area receives some individual subassemblies directly from the SMKT. These subassemblies are typically customized options requested by customers; they do not belong to the basic platform of the machine and as such don't require assembly and testing on the flow line. These parts need to be pulled by the shipping via SAP, and then collected at the SMKT once they are completed. This process requires many extra labor hours for each machine.

Second, spares and specialties are transported from the warehouse directly to the shipping area in forms of bins and cages. At the shipping area, those parts will be reconfigured into other bins for reasons listed in Table 1.

Third, the parts sent from the warehouse as part of the 'final assembly' kits require some extra work performed by shipping workers. Final assembly kits represent for the parts that will only be used for on-site installation including doors, subfloors and walls, as well as some harnesses, cables and small subassemblies. As discussed in section 2.2.8, the miscellaneous parts (including the final assembly kits) will follow different paths depending on the machine they belong to.

Figure 9 below shows the miscellaneous parts flow to shipping. The shaded zone represents some of the tasks in the shipping area. To summarize, the shipping area has many inputs; also it has several extra tasks that are not supposed to be the responsibility of the shipping process. Poor standardization of tasks and varying parts flow also add to the lead time, while lack of communication results in problems of parts missing, leading to efficiency losses and increases in waiting time.

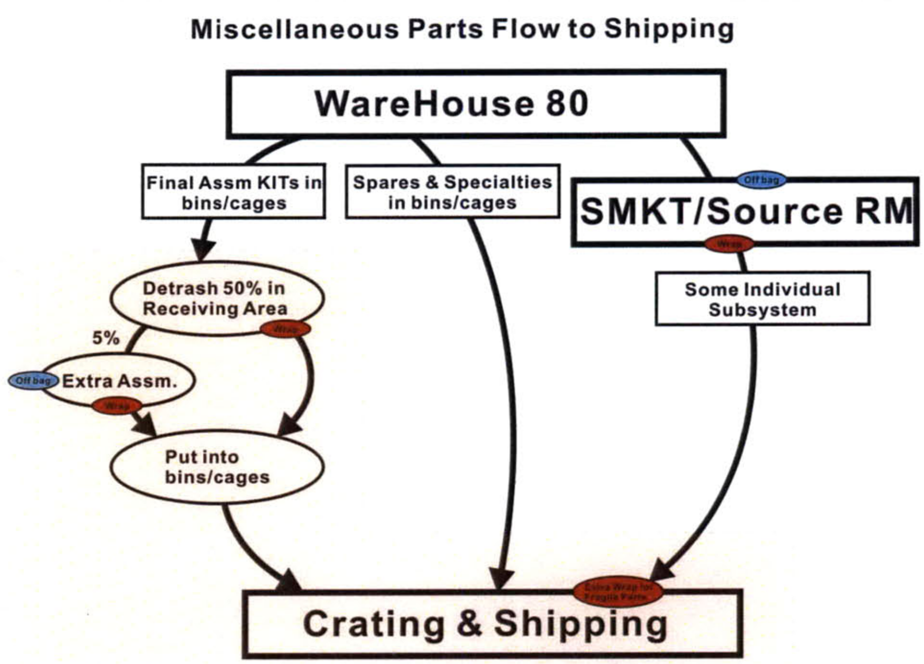

Figure 9: Miscellaneous parts flow to shipping

3.1.3 Inefficiency of checking miscellaneous parts

The current packing-shipping process takes between 120 and 140 labor hours per machine for SmartShip orders, accounting for one-fourth of the total manufacturing labor time, which is considered to be a high proportion in manufacturing industry. One of the major explanations found to the long packing-shipping time is that the workers count and check parts manually, which is labor intensive and time consuming.

The task of manually verifying the shipment contents in the shipping area (shown as 'parts check out' in Table 1) adds up to 10 hours to the process without adding value to the product. Indeed, the contents of the various bins and cages received from the warehouse will have already been checked there, and the repetition of this visual verification merely serves as a means of extra precaution. Since this task is a repeated, time-consuming and no-value-added process, replacing it by a more an efficient way to check out parts could help achieve a better parts flow.

A similar verification process also happens in the warehouse kitroom, as well as in the main building receiving area, where material carts are prepared. A more efficient process could also be extended to these areas.

3.2 Fraudulent Claims and Warranty Costs

VSEA products are expensive machines that are put to work in difficult environments at the client site. As such, failure of a machine component can cost VSEA customers several thousand dollars in replacement parts. Attempts to make fraudulent warranty claims have been witnessed, whereby a failed part from an old machine would be returned and claimed as new (from a more recent shipment still under warranty) in order to avoid purchasing replacement parts. With no reliable way to track a component to a given machine, VSEA has sometimes been unable and unwilling to debate these claims.

This type of fraudulent claims occur once a month on average at VSEA, and it has been estimated to cost VSEA about $100,000 per year on average, not counting time spent on investigation, troubleshooting and production of the replacement part.

The lack of traceability of the components has also resulted in shortened supplier warranties, whereby a third-party supplier would offer warranty of a given component for a given period of time (e.g. one year) from the date of delivery to VSEA. VSEA, in turn, will offer (in this example) a one year warranty to the end customers, starting on the delivery date of the machine. This means the component in question is under warranty from the supplier while in VSEA's inventory, but not during the last few months of VSEA's warranty period to the customer. A large portion of VSEA's yearly warranty liabilities stems from such late-term warranty claims.

3.3 Deficient tracking ability

Varian has a flexible assembly system for low volume and high diversity production. Although the machines are categorized into only three series and seven main types, each machine is customized for many reasons. For example, the power supply differs by country; some customer requires modification of machine configuration to fit for their on-site installation; others will select their own spares and specialties to realize specific functions. Moreover, a single part number may encompass different revisions and sizes. All these aspects require the manufacturing structure to guarantee the right flexibility.

Such a high flexibility leads to dedicated parts for each particular machine. Tracking a given part of a machine has been called for by different departments of the company.

3.3.1 Individual part tracking

At present, VSEA has no reliable method to track information such as part type, part number, part revision, manufacturer, delivery date and warranty status. This type of information can be invaluable for the company. For instance, in the event of a machine component breakdown at the customer site, the company should have the capability to immediately define the broken part, find out the upstream supplier, and check the warranty status to see who will be responsible for fixing or replacing the part.

Poor traceability also prevents VSEA from tracking the performance of each type of parts – which parts always have problems, or which parts are robust enough. The company therefore has difficulties evaluating the suppliers based on the performance of their parts, making supply chain improvements slower.

3.3.2 Machine configuration tracking

As we stated before, all the machines are customized. The base platform of a machine consists of around 60% of total parts. The rest consists of customized parts, spares, and specialty items. The different configurations are dictated by multiple reasons, including specific machine functionality, particulars of on-site installation, power difference in different countries and other customer preferences. In general, each customer will tend to order the same or similar configurations. At present, VSEA has no reliable way of keeping record of the configuration of outgoing machines, and therefore has to re-create a custom PBO (see section 2.1.1) each time a customer orders a new machine, regardless of how similar the machine is to the previous customer order.

3.3.3 Part flow tracking system

For long-term operation of VSEA's assembly line, the ability to track parts throughout the assembly process will help smooth both parts and information flow.

An internal part flow tracking will enable real-time locating of the components. In other words, the tracking systems can determine where in the facility a given part or subassembly is, what station it will go to next, as well as which machine it belongs to. Such a tracking system will eliminate loss or misplacement of parts and reduce delays attributed to:

1) Parts misplaced between process steps
2) Parts mistakenly taken for a different machine
3) Parts delivered to the wrong place
4) Parts shortages
5) Lag between SAP updates on part location and the actual physical location of the part.

These problems require the assembly workers to spend a large amount of time looking for parts, making phone calls or even placing new part orders.

If parts are tracked in the internal supply chain, shortages will be known at all times and addressed; parts misplaced during assembly will trigger an alert once the module moves to the next assembly station; parts assigned to a given machine will be clearly marked and thus may not be taken by mistake; constant tracking will eliminate the gap between physical part delivery and system display and signal faulty deliveries.

4. Review of Theoretical Background and Previous Work

The findings of the previous chapter have made clear the need for an efficient parts tracking system at various levels of VSEA's facility. This chapter starts by underlining the versatility of RFID and presenting successful real-world application cases where the technology was used in contexts relevant to the project discussed here, warranting its use at VSEA. The remainder of this chapter presents an overview of the technology and the challenges it presents, as well as guidelines for the experiments to be performed.

4.1 RFID Application Cases

Because of RFID technology's unique characteristics, it has been widely used in different areas, including the manufacturing and retail industries, logistics, healthcare, security and public infrastructure. A selection of real-world application cases is presented in Table 2. Despite their diverging nature, these cases share the same results, in that they show RFID can help reduce complexity and operation time, eliminate errors and save labor costs. The applications with particular relevance to VSEA's operations are discussed further in sections 4.1.1-4.1.3.

Table 2: RFID application area (including pilots)

Area	Methodology	Company
Retail/ consumer	Automatic checkout, simplify transaction Inventory management. Storage control	Wal-Mart [7] METRO Group [8] Procter & Gamble [9]
Logistics	Track truck, pallets, containers	JR Freight [10]

	in transportation	Sony logistics [11]
Manufacturing	Check parts in process Track key parts in use Inventory management	Boeing [12] Volkswagen [13] Intel [14]
Pharmaceutical	Product Authentication and Drug Pedigree Packaging and logistics	AstraZeneca [15] Pfizer [16] Cephalon, Inc. [17]
Healthcare	Track patients to speed up check-ups	Apollo Hospital Chennai [18]
Security	Identity check	Bob Jones University (car entry) [19]; US department of Homeland Security [20]
Public sector	Identify individual persons, cars, or other assets	Highway "EZ-Pass" [21] Los Angeles Marathon [22]

4.1.1 Boeing: Tracking of Key Components [12]

Boeing's 787 jets are assembled on a super-sized assembly line and comprise several hundred thousands of parts. After identifying 1,700 to 2,000 'mission-critical' parts (defined as parts that expensive or require frequent maintenance and replacement), Boeing chose RFID to track each of them during the assembly of its 787 jetliners. Previous attempts to use barcodes for the purpose of tracking mission-critical parts failed due to some barcode label being unreachable by the scanner. In contrast, RFID supports "non-visual reads", allowing detection of tags without line of sight, thus enabling quick and reliable location of critical components.

Similar to Boeing, Varian's ion implanters are highly complex machines containing hundreds of high-value components often assembled in hard-to-reach positions. Tracking these critical parts in a convenient way is valuable for the purpose of maintenance and warranty, and can be done through RFID.

4.1.2 Japan Rail Freight: Container Tracking [10]

JR Freight provides cargo transportation service by rail in Japan. At each stop, large steel containers are off-loaded from the railcars and stacked. Keeping track of several hundreds of containers previously involved tedious, time-consuming manual labor, whereby JRF operators had to walk along the terminal and log the containers' loading arrangement by hand. JRF's switch has automated this process: both containers and railcars are equipped with RFID tags, and they are paired together upon unloading, so as to easily keep an accurate and up-to-date record of the incoming and outgoing container configurations, and direct loading operations.

Such a linkage between individual parts and their parent assembly can help VSEA achieve instantaneous and complete module configuration logging. High-value components could be linked to the module they were assembled on, which in turn would be linked to the parent machine, and thus a complete configuration record could be kept for each customer.

4.1.3 Stillage Tracking [23]

A European automotive OEM in the automotive industry uses specially designed stillages to carry different automobile parts produced by outside suppliers. To address stillage shortage, due to mishandling or misplacement by loaders, truck drivers or warehouse workers, the OEM chose an RFID-enabled solution, whereby each stillage, tagged by a unique RFID transponder, is checked both at the supplier site and upon receipt by the OEM. The gates of the warehouse are selected as the optimum places to read the tags and capture all stillage movements.

The concept of gate checking is a possible embodiment of RFID implementation at VSEA. Finished machine or parts container would be inventoried using such RFID-enabled 'gates' instead of being manually counted, with inventory information transmitted in real time to a central computer system for quick remedy to potential problems.

4.1.4 Expected Benefits of RFID in Varian:

In light of the preceding cases, RFID is deemed a suitable technology for VSEA's environment, and is expected to provide benefits at several levels:

1) *Efficiency through Automation*

Replacement of manual inspection of parts with automated RFID-checking at multiple stages substantially expedites the part checking process.

2) *Accuracy:*

Continuous RFID-inspection of containers reduces the potential for erroneous parts picking and overlooked mistakes.

3) *Visibility:*

The unique EPC code on each RFID tag could be associated with Purchase order for every single part, enabling supplier evaluation and early detection of frequently defective parts.

4) *Authentication:*

For high-value parts, unique EPC codes linked to each part's serial number will allow authentication of warranty claims.

4.2 Components of a Typical RFID System

As shown in Figure 10, a typical RFID system consists of a tag, a reader, a host computer and a reader antenna. RFID systems work in the following way: the reader transmits a modulated signal through the antenna, which the tag antenna receives. The signal is processed by the tag's integrated circuit and a backscattered signal containing tag information (usually in the form of an Electronic Product Code – or EPC – which is unique to each tag) is emitted back to the reader, which demodulates the received signal and sends it to a host computer. The reader software in the host computer can then display the tag information and show the information about the tagged item by linking the tag to a relevant database. [24]

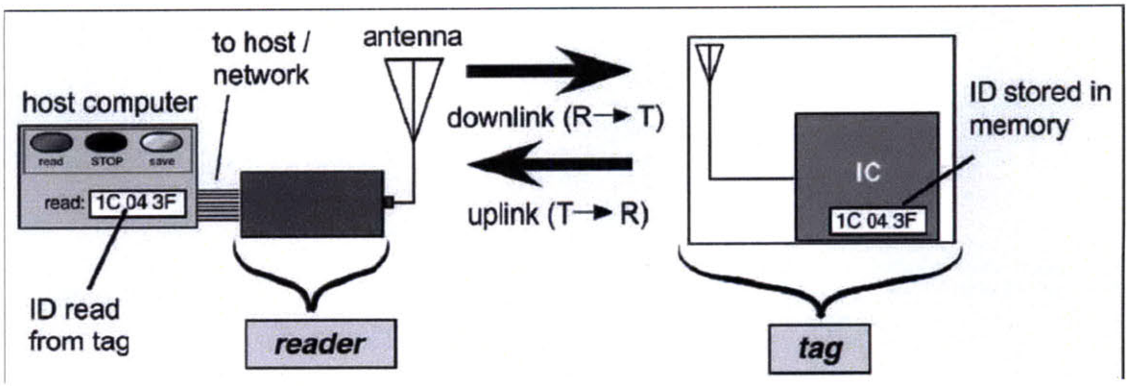

Figure 10: Overview of a typical RFID System [7]

The frequency of RFID systems varies from around 100 KHz to over 5 GHz, so from (1) (where λ is the wavelength, f is the frequency and c is a constant) we can calculate the corresponding wavelengths which are found to be as small as 10 cm and as large as 1 km.

$$\lambda = c/f \tag{1}$$

RFID systems can be categorized by whether the wavelength is comparable in size to the tag antenna, which can be as large as 1 m in diameter or as small as 1-4 cm. When the wavelength is much larger than the antenna, the systems are typically inductively coupled as all the available energy from the reader antenna is contained within a region near the reader antenna and the phase delay between transmitted signal and backscattered signal is much smaller than the time between peaks (the signal will travel 4ns to reach a tag at the distance of 1.5 m, or about 6% of the RF cycle at 13.56 MHz) making it hard to discriminate both signals. In contrast, high or ultra high frequency RFID systems usually use radiative coupling to communicate between the reader and tag. (Shown in Fig 11) [24]

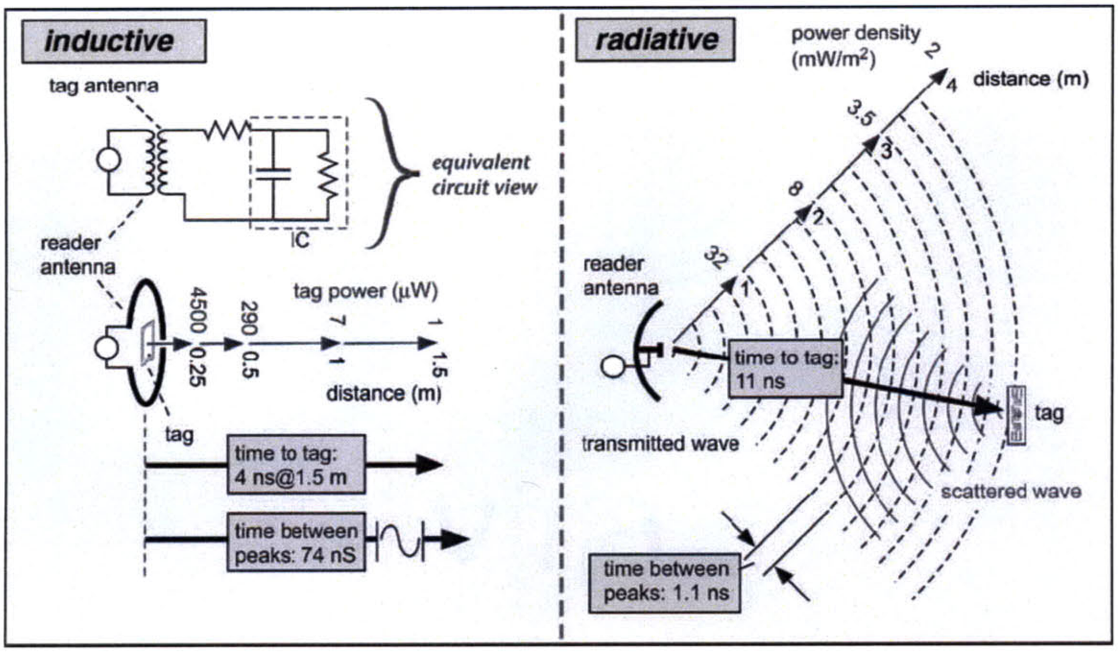

Figure 11: Inductive Coupling (13.56 MHz, 50 cm diameter antenna) vs. Radiative Coupling (900 MHz), With Associated Power and Time Delays [24]

In the application discussed here, an Ultra High Frequency (UHF) RFID system was chosen to gain as wide a read zone as possible. However, the drawback is a complicated read zone. Because the power falls slowly with distance, and the wavelength is small compared to typical tag-reader distances, reflections from distant obstacles can propagate back into the region of interest and interfere with the waves launched by the reader antenna. As shown in Fig 10, even in a simple room with an RFID transmitter at the center, the energy distribution is not continuous and difficult to predict. With typical read energies (Energy required to activate the tag's IC and scatter the reader signal back) larger than -10 dB, the figure shows the existence of unreliable read zones between 2 to 4 m away from the reader antenna. The presence of multiple tags amplifies this problem.

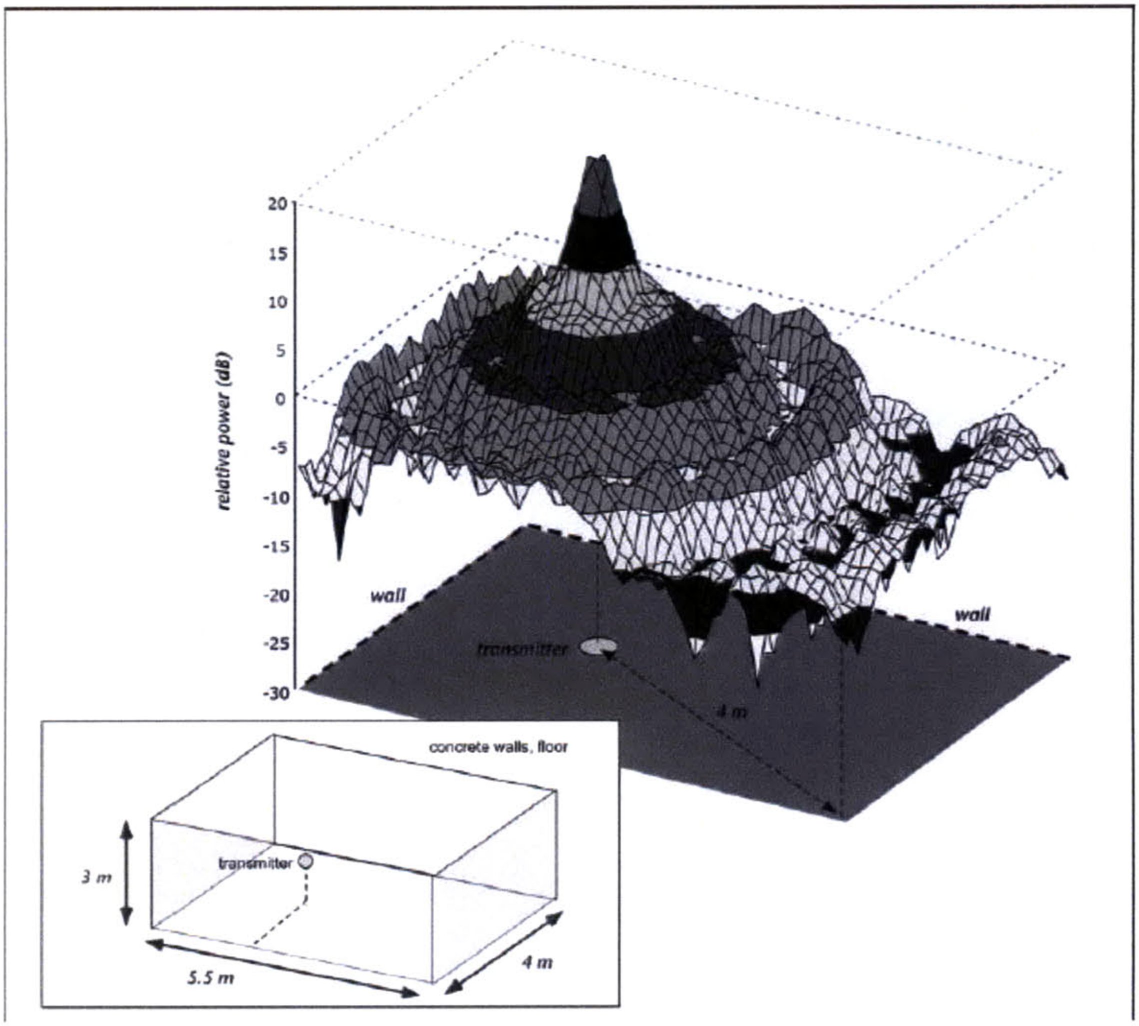

Figure 12: Simple Model of Power Density in a Room with Partially Reflecting Walls and Floor [24]

When designing an RFID system, one must also be aware of skin depth, which indicates the ability of radio waves to penetrate obstacles such as metal and water. For instance, as evident from (2) and Table 2, the skin depth for metal is very small. Therefore even a thin piece of metal can cancel a radio wave. Therefore, when there are many metal parts in the read zone, the reliable read area is restricted and randomly located. The skin depth is given by

$$\delta = \sqrt{\frac{1}{\pi\mu\sigma f}} \quad (2)$$

Where f is the wave frequency, σ is the conductivity and μ is the magnetic permeability.

Table 3: Depth for Various Common Materials [24]

Material	Skin Depth At			
	125 kHz	13.56 MHz	900 MHz	2.4 GHz
Tap water	8 m	2 m	4 cm	8 mm
Animal tissue	2 m	60 cm	2 cm	8 mm
Aluminium	0.23 mm	71 μm	2.7 μm	1.6 μm
Copper	0.18 mm	55 μm	2.1 μm	1.3 μm

$1\,\mu m = 10^{-6}\,m$

4.3 Metal Interference

The tag antenna is critical to signal exchange in an RFID system. However, the performance of the tag antenna is influenced by its immediate environment. For example, when a tag is attached on metal surface, it typically cannot receive or transmit signal. The impossibility to read RFID tags from a distance greater than a few centimeters in metal environments has partially limited the success of the technology and its application to supply chain. There are two main reasons for this behavior: eddy or mirror current in the metal surface and detuning. Eddy currents consume the energy from the radiation wave, so that the tag antenna cannot receive enough energy to work. The detuning involves energy drain caused by the electromagnetic "friction" from the metal. [25], [26]

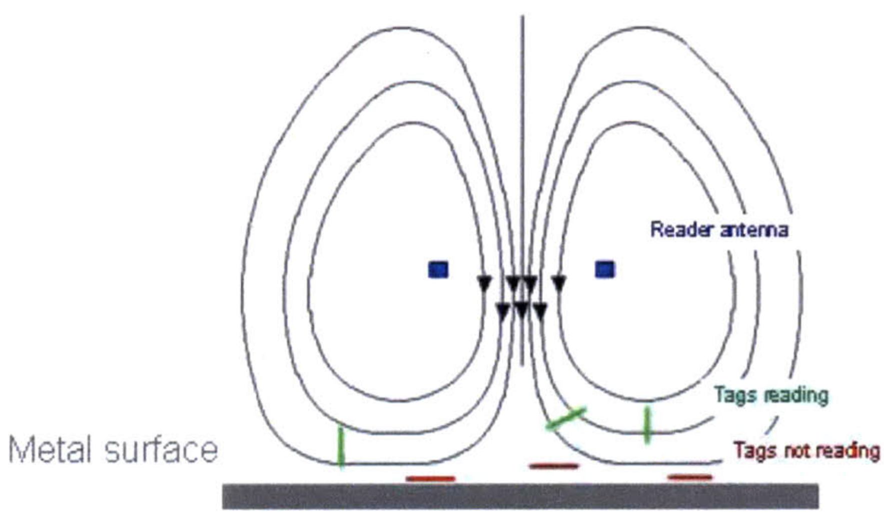

Figure 13: The perpendicular magnetic field's effect [25]

As shown in Figure 13, metal causes eddy currents in the vicinity of the RFID reader antenna which absorb RF energy, thus reducing overall effectiveness of the RFID field. In addition to this, the eddy currents also create their own magnetic field that is perpendicular to the metal surface, cancelling the read field further.

Metal can also detune both reader and tag antenna, leading to added parasitic capacitance which reduces system performance.

Based on Adam's [25] and Deavours' [27] research on tags used in metal environment, several suggestions we found to enhance the performance of passive tags in such applications:

1. Design the correct tag antenna including ferrite-cored transponder coils. The high permeability of the ferrite core allows a small transponder to be energized by the weaker field that exists close to the metal surface. [25]
2. Pick the right frequency. The higher frequency could get the wider read zone, but suffers more energy loss due to eddy currents and parasitic capacitance. [25]
3. Increase the distance between tags and metal using a dielectric spacer. [27]

4.4 Electromagnetic Interference

The presence of electromagnetic interference (EMI) will affect the detectability and read range of tags, especially in an environment with heavy electrical equipment. [28] The interference is significant when the RFID system is located in a similar electromagnetic radio frequency environment. For example, the authorized frequency band for UHF RFID in Europe is 868MHz, which is very close to the mobile network GSM 900 MHz-band. In some cases, the operation of a mobile network will greatly affects the read range of RFID system. [29]

In [28] Cheng suggests some feasible measures to alleviate problems stemming from EMI in RFID application:

1. Before implementing an RFID system, it is necessary to conduct an EMI investigation. Based on the mapping of the EMI environment, choosing suitable RFID equipment and placement will optimize tag detectability.
2. Attaching tags as far away from power sources as possible in manufacturing facilities can reduce the EMI effect.

4.5 Design of Experiments

RFID is a highly versatile technology that can be adapted to many applications. However, factors specific to the implementation environment must be taken into account and a pilot project can detect problem areas ahead of full implementation. This section presents background relevant to the design and conduct of the pilot project under discussion, and the analysis of the results obtained from it.

4.5.1 Arch Setup

The vision that was explored for the implementation of RFID in both the kit room at the warehouse and the shipping area in the main building relies on a check-in/check-out 'arch' setup where the contents of bins or cages of tagged items are checked for accuracy. Understanding the expected behavior of such arches in a theoretical RFID setup is critical to a successful implementation in real-world applications.

This theoretical behavior or a multiple reader portal is explored by Wang et al. in [30], where a simple setup with n antennas, which can take any of N potential positions, is considered. The 'tag space' is divided into a set of discrete positions, while the set of possible orientations of each tag is discretized using Rusin's algorithm [31] to approximate a uniform spherical distribution. Using Friis' equation to find the power received by the tag for each possible combination, the author builds α% read zones, which are to be understood as delimiting the regions with an upper bound read accuracy of α %.

4.5.2 DOE for tag and antenna placement

Beyond the general rules of thumb provided by the above, any field implementation of RFID must be preceded by extensive testing. The topic of Design of Experiments (DOE) for RFID applications is therefore currently the object of active research.

In [32], McCarthy at al. look at the various parameters, including inlay design, conveyor speed and reader type, as applied to the tracking of packaged meat. In [33], Hoong focuses on a 3 factor experiment (Power, bending diameter and tag orientation) to derive a linear model for read distance, while in [34] Ammu et al. explore how readability is affected by the tag-antenna distance as well as metal and electromagnetic interference.

4.5.3 Tag Plane Array Effects and Tag Collision

In considering whether to tag individual parts, bags of parts or entire bins, one must consider the effect of tag collision and shadowing. In [35] Weigand and Dobkin present a theoretical discussion of tag plane array effects, showing multiple densely packed planes of RFID tags will exhibit significant interference effects.

In [25], several possible solutions are proposed to enhance reliability of tag readings in an environment where several tagged parts are packed in a dense fashion (such as in a shipping bin):

1. Having the parts in motion increases the chance for parts to be read
2. Optimizing the set of multiple reader antennas, such as the number, placement and angle of antennas, could increase the probability of all tags being read.
3. Applying multiple tags on a single part, filtering duplicate reads by software.

5. Methodology

Based on the study of the previous cases and RFID features, it is believed that introducing an RFID system is the core idea to automate the internal checking process and to improve the ability to track parts in VSEA, and in turn lead to long-term cost saving.

Corresponding to the three major problems stated in Chapter 3, the project contains three different phases that address each of the problems respectively. However, RFID technology plays the major role in all of the phases. Also, it is envisioned that different solutions of all the phases can be integrated into an entire RFID system. The three phases are summarized as follows and will be discussed in detail in Chapters 6, 7, and 8:

1. RFID for miscellaneous parts checking
   Expectation: Once bins/cages of parts go through a RFID checking arch, all the tagged parts are sensed and displayed on the computer; no more manually checking is required.
2. RFID for module parts tracking (high value parts)
   Expectation: Once a module is ready for package-shipping, it goes through RFID checking and all the tagged high-value components are recorded by the central system; the detailed information of each part is collected for future maintenance.
3. RFID for flow line part tracking
   Expectation: The tagged flow line kits/subassemblies are checked in and checked out at multiple stages, especially at the flow line; the Work-In-Process will be entirely visible in a system view.

To reach this stage of RFID implementation throughout the entire manufacturing line, the following methods are taken to drive the project.

1. Verify the RFID technology

2. Redesign the parts flow process
3. Simulate the manufacturing system

5.1 Verify the RFID technology

Although RFID technology has been widely used in many industries and proved to be applicable and helpful, its usage in Varian's environment still requires extra test because of the uncertainties. For instance, the effect of metal and electromagnetic interference of sensing RFID tags remain unclear in Varian's plant which is filled with metal, magnets and electronics; the RFID tag collision effects is difficult to estimate from literature; the read range should be defined, which decide how much convenience it can bring; the read accuracy is also a parameter that indicates the reliability of the RFID system.

Taking into consideration the following concerns, a set of RFID equipment, together with over 20 types of RFID tags, was purchased for testing. Based on the envisioned system, experiments were designed to test the performance of the equipment. This section describes the preparations of the experiment. More details of experiments are discussed in Rui Jia's thesis [36] and Cyril Koniski's thesis [37].

5.1.1 Equipment description

For the practical pilot implementation in VSEA, an IMPINJ RFID reader evaluation kit, an ATID handheld reader and a tag evaluation kit were chosen. The IMPINJ reader kit consists of a Speedway reader, two Farfield antennas, a Brickyard antenna and a Mini Guardrail antenna. The Speedway reader can be powered over etherrnet or cellular modem and has 4 antenna port configurations. Reading and writing are controlled by software on the host computer. The ATID handheld reader is integrated with software, reader and antenna into one, so it is portable but has less powerful in transmitting signal.

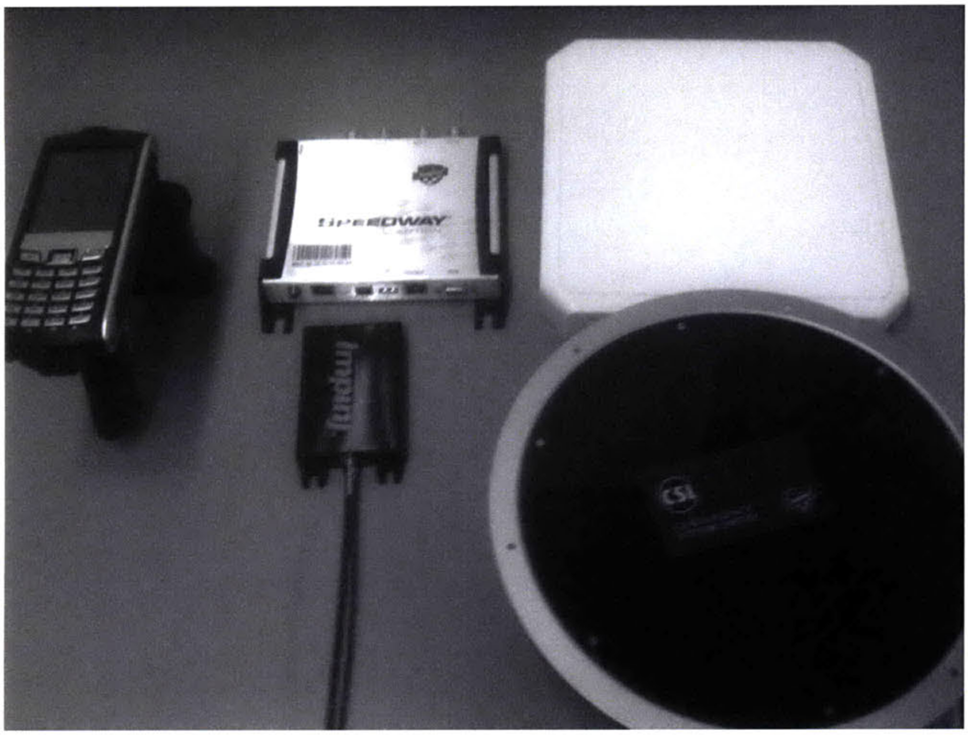

Figure 14: RFID equipment

5.1.2 Experiment design

The experiments were designed for RFID application of Phase I and Phase II. In Phase I, parts in bins/cages that come from the warehouse were tagged and then checked by being pushed through an RFID arch. The sensibility and correctness of the system were the key issues to be evaluated in this experiment. The parameters such as antenna power, arch size and types of tags were tested, which finally led to the best combination for implementation [37]. In Phase II, parts on the modules, which exposed to an environment full of metal, were checked with both the RFID arch and the handheld reader. The tag placement, type of tags and arch size were tested to reach the best tag-sensing percentage [36]. Both of the experiments provided results of RFID system performance and setup requirements, which addressed the technical problems of implementing RFID in VSEA.

5.2 Redesign the parts flow process

Instead of simply introducing a new technology, modification of the parts flow process is necessary in order to meet the requirements of the new system and maximize the positive effects. Therefore, the project involves analyzing the internal supply chain and redesigning some of the parts flow.

5.2.1 Adjust the existing parts flow processes for RFID application

The basic adjustment to the existing processes at VSEA is to insert tag-attaching (tagging) procedures and tag-checking (checking) procedures at different stages in the entire production chain. The goal is to determine the best stages for these procedures and detail how they should be implemented.

Based on the high-level material flow, preliminary selections of the stages where the tagging/checking processes should take place are listed in Table 4.

Table 4: Preliminary selection of tagging and checking stages

Tagging stages	Checking stages
Supplier (parts preparing)	Warehouse Kit Room (parts outgoing)
Warehouse Receiving (parts registration)	Main Building Receiving (parts coming in)
Warehouse Sorting (parts classification)	Clean Room (extra assembly completion)
Warehouse Kit Room (kits preparing)	Air Shower (module completion)
Supermarket (subassembly preparing)	Shipping Area (machine completion)
Flow line (module preparing)	

The existing operational procedures of most of the above stages were captured in detail to determine the best place and best way to add the tags as well as check the tags. Chapter 2 reveals the functions and operation procedures of each stage.

After examining the tasks at each stage, the advantages and constrains of implementing RFID at each stages are compared in Table 5 and 6.

Table 5: Comparison of stages for implementation of phase I

Phase I: RFID application for miscellaneous parts checking		
Tagging Stage	**Advantages**	**Constrains**
Supplier	Avoid in-house tagging	Long-term training of suppliers
Warehouse Receiving	Easy to link tags to part info	Individual parts requiring tagging are still sealed in boxes
Warehouse Sorting	Individual parts are unsealed from boxes and easy to tag	Part info are in SAP; need extra SAP search to link tag to part info
Warehouse Kit Room	Tagging only the selected parts is available	Part info are in SAP; need extra search to link tag to part info
Checking Stage	**Advantages**	**Constrains**
Main Bldg. Receiving	Check and confirm parts before distribution	Complex working environment: de-trash, part registration etc.
Air Shower	Speed checking is useful for bins and cages of parts here	Benefits of automatic checking is lost because of extra assembly
Shipping Area	Speed checking is useful for bins and cages of parts here	Parts are reconfigured between bins

Table 6: Comparison of stages for implementation of phase II

Phase II: RFID application for module parts checking		
Tagging Stage	**Advantages**	**Constrains**
Supplier	Avoid in-house tagging	Long-term training of supplier
Warehouse Receiving	Easy to link tags to part info	Individual parts requiring tagging are still sealed in boxes
Main Bldg. Receiving	Easy to link tags to part info	Complex working environment: de-trash, part registration etc.
Supermarket	Tag the subassemblies finished in house	No obvious constrains
Checking Stage	**Advantages**	**Constrains**
Flow line air shower	Confirm production right after module completion	No obvious constrains

Air shower	Confirm production right before shipping to customer	No obvious constrains

Based on the comparison of inserting RFID processes at different stages, together with the company's potential resources, the final selection is described in Chapter 7 and 8 as results. Also, the new procedures are standardized as instructions for operators.

5.2.2 Remap parts flow process for lean consideration

The manufacturing engineering philosophy is based on designing a manufacturing system that blends together the fundamentals of minimizing cost and maximizing profit. These fundamentals are Man (Labor), Material and Machines (Equipment) (3M). [38] The application of RFID system will bring the following "3M" issues to VSEA, which affects the benefits of the RFID system:

1. Utilization of RFID equipment

   A set of robust RFID equipment, composed of at least one reader and several antennas, is expensive. One of the goals is to purchase as few RFID readers as possible, but use them as much as possible. Therefore, only those places with high part flow will be selected for RFID setup.

2. Labor dedication

   For a flowing manufacturing system, people are highly utilized when they are dedicated to certain work. The RFID application in VSEA brings new considerations of task distribution among multiple stages. Procedures related to part flow will be redesigned under the principle of labor dedication.

3. Smooth material flow

   The RFID checking system is used at critical stages to check and track part status. The precondition of this is to define a standard part flow that both the central system and the supervisors can easily follow. Smoothing the material flow will be helpful to 1) adding RFID processes throughout the manufacturing line, 2) launching cycle time analysis stage by stage, and 3) evaluating the performance of both the current manufacturing line and the new one with RFID.

Based on these lean principles and VSEA's resources, the miscellaneous part flows were redesigned to meet the needs of Phase I implementation (see solutions in Chapter 6). The solutions were discussed with the manufacturing managers in VSEA to evaluate the feasibility. Phase II and Phase III covers fewer flow changes except adding the tagging and checking procedures.

5.3 Simulate the manufacturing system

In this project, the computer-based simulation was used for Phase III – RFID for flow line part tracking, to estimate the performance of the assembly processes. The simulation is supposed to reveal the hidden problems in the existing manufacturing system. With RFID suggestions being considered, the simulation was then applied to forecast the new performance of the system. The simulation preparation is discussed in this section, and the results are displayed in Chapter 8.

5.3.1 Introduction of simulation tool

CellSim is the software that was applied for simulation of VSEA's manufacturing process. CellSim is a simple factory simulator developed by John O. McClain of Cornell University. The software is free of charge and can be used in any manner as asserted by the developer. Program Files may be downloaded at: *http://www.johnson.cornell.edu/faculty/mcclain/*.

CellSim can be used to simulate basic manufacturing lines. The two basic elements in the simulation, Machine and Storage (buffers), can be converted to fit different manufacturing procedures and inventories respectively. The Machine has multiple parameters that can be set as inputs, such as Mean Time To Failure (MTTF), Mean Time To Repair (MTTR), ability to process multiple work, process time for each product, scrap rate etc.; while the Storage can be set with a designed capacity. Different Machines and Storages can be linked to each other and form a manufacturing system; arrows representing directions of part flow can be added. Advanced features include Kanban control, priority order control, rework flow, fixed quantity arrival and so on, which enables the model to be fit with complex systems more accurately.

The simulation model of the VSEA production line was created; parameters of each workstation and storage area were set based on data captured at the plant. However, some assumptions were made to complete the model. The resulting simulation animation would display the work status of each machine (set up, normal run, starving, blocked, down) and inventory level in real time. After each simulation, an exported worksheet reveals machine utilization, machine performance record, final inventory level, parts produced etc. Both the real-time animation and the final worksheet indicate the performance of the real manufacturing line.

The simulation model was first established to fit the actual manufacturing system. Problems suggested by the simulation results was analyzed and compared to those in the production line. After a system optimization, new parameters were entered into the simulation to assess the improvement.

5.3.2 Model

According to the current production line, the material flow was defined as displayed in Figure 15, which is the reference of the simulation model.

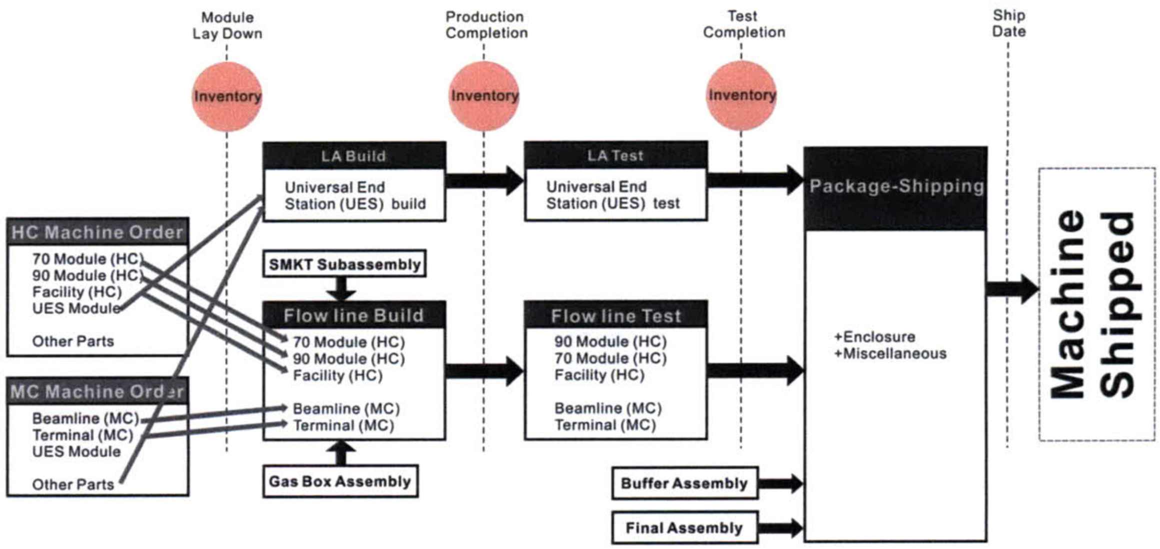

Figure 15: Material flow for simulation

The main flow is the module production flow which almost covers the entire production lead time, while the other flows such as SMKT Subassembly, Gas Box Assembly, Buffer Assembly and Final Assembly go in parallel with the module flow. Although these flows also cost some labor hours, they rarely contribute to the entire lead-time.

Once an order comes, it splits into several modules and each follows its own branching production lines. For each machine order, the modules may not be laid down and start to be assembled at the same time. Some modules are laid down earlier if its production line has capacity.

The material flow map led to the simulation model (see Figure 16). The grey cells represent workstations, while the blue cells are storage areas for corresponding upstream working processes. The cells named as "Sof" and "Pool" are only to help organize the model, not representing any physical operation.

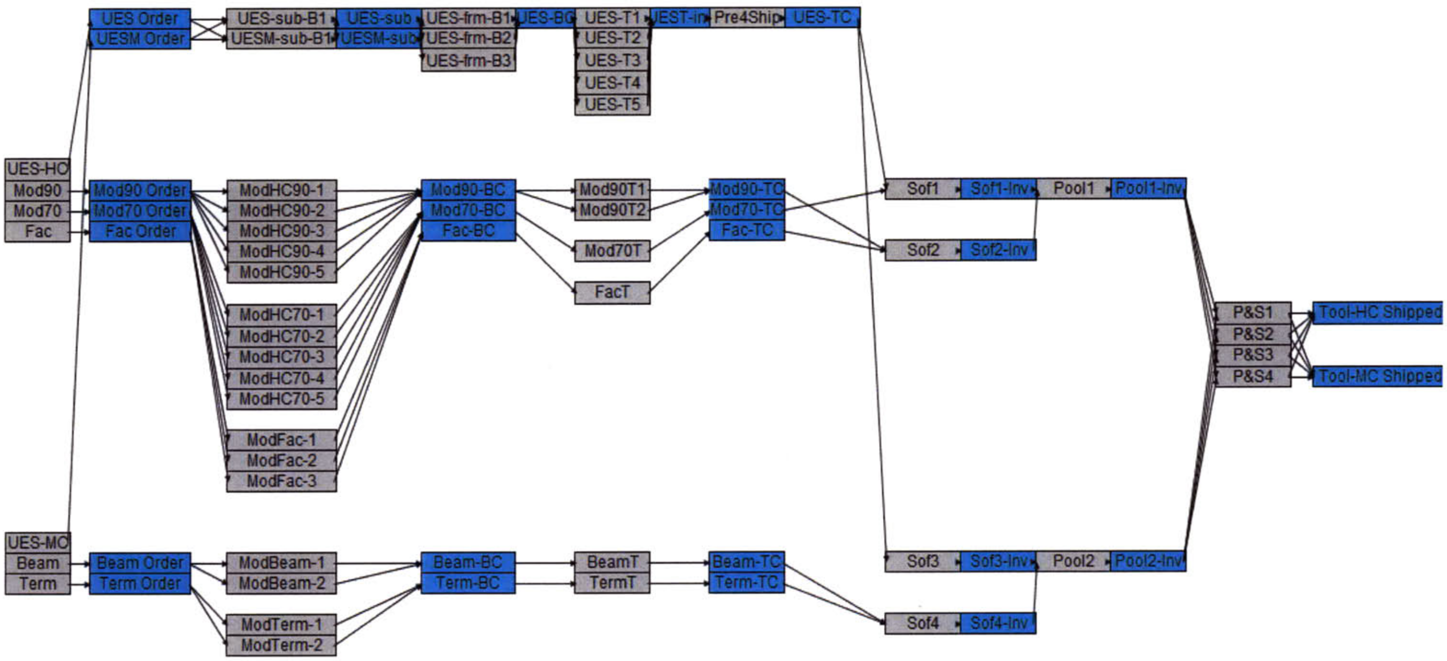

Figure 16: Simulation Model

5.3.3 Assumptions

The simulation only covered the production flow of Medium Current machine and High Current Machine with SmartShip. Other types of machines of much lower volume, such as High Energy Machine, PLAD, SOLION, were not included in this model. To capture the current performance of Varian's manufacturing system, the latest records, forecasts, and on-site resources were used to set parameters in the model. The simulation applied DAY as the basic time unit, considering the scope of entire cycle time. Since VSEA has roughly half manpower at weekends, 6 working days were counted for each week, leading to 78 days for a quarter. The simulation was run for a quarter cycle.

5.3.2.1 – Demand:

The demand data came from records of issued machine orders from February 1st, 2010 to the July 1st, 2010. 90 machines were laid down for production during the five-month period, with 70% HC machine and 30% MC machine. The annual demand was then calculated to be 216 machines. The breakdown of annual demand and TAKT time are listed in Table 7.

Table 7: Current annual demand and TAKT time

HC Machine	151 tools/year
MC Machine	65 tools/year
Total HC & MC	216 tools /year
Days per year	312 days/year
Total TAKT time	1.44 day
HC TAKT time	2.07 day
MC TAKT time	4.8 day

To simulate the incoming order, the customers were regarded as an "upstream machine" that produced orders at a steady rate. It was reasonable to regard the rate as steady because production planners always adjust the machine lay-down date despite the fluctuation of order coming rates. The production cycle time of this "upstream machine" is equal to the TAKT time listed in Table 7.

5.3.2.2 – Workstations

The cycle time of module build / module test is highly variable. The peak falls at around 5 days; however, the deviation is considerable and the distribution tails are asymmetrical. The distributions graphs of UES (Universal End Station module) testing process and UES building process are shown in Figures 17 and 18. The original data is attached in the appendix.

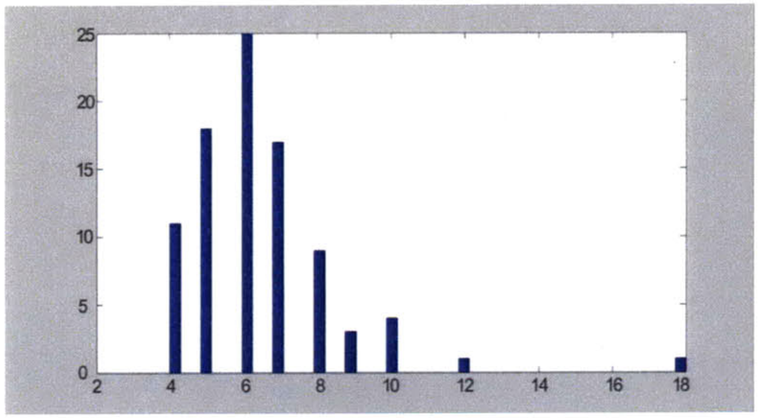

Figure 17: Cycle time distribution of UES testing (data from Feb 2010 to June 2010)

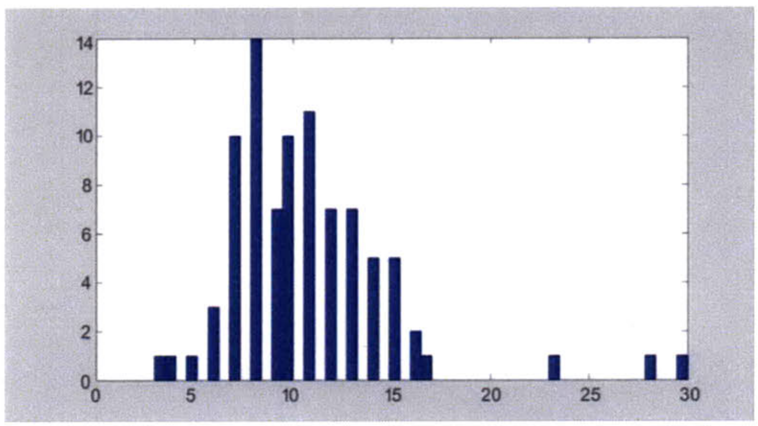

Figure 18: Cycle time distribution of UES building (data from Feb 2010 to June 2010)

This distribution shape can be interpreted by the characteristics of Varian's cell work. Each module build/test job has a standard working procedure which the workers need to follow. As long as the module is a standard one with few modification, and nothing unexpected happens during the process, the module build/test job can be finished within the standard cycle time (eg. 6 days for UES testing), even one/two day earlier sometimes if the assemblers perform perfect. However, the cycle time cannot be as low as less than 4 days for UES testing because of the certain amount of work. Therefore, the left tail of either graph is short.

However, missing parts and inventory shortages are common causes of delaying processes; some lack of parts can be solved within half day or one day, but occasionally, if the part is out of stock and requires a long delivery time, the job has to wait for several days. Also, many of the machines require "options" and "special" work which takes more time. In general, it is usual for module jobs to take longer than 6 days to finish; in some worse cases, the cycle time can be very long. The right tails of the graphs suggest the reality.

Considering the features discussed above, the distribution model in Figure 19 (left) was selected to match the assumptions. The model was an approximation using the Generalised Lambda Distribution (Ramberg and Schmeiser's generalization of Tukey's Lamda).

$$F^{-1}(p) = \lambda_1 + \frac{P^{\lambda_3} - (1-P)^{\lambda_4}}{\lambda_2} \quad [39]$$

λ_1: location parameter

λ_2: scale parameter

λ_3: shape parameter (skewness)

λ_4: shape parameter (kurtosis)

In this simulation, the software only provided bar control to adjust the shape of the distribution, instead of inputting parameters. Figure 19 (right) also shows how to set the parameters for defining the distribution.

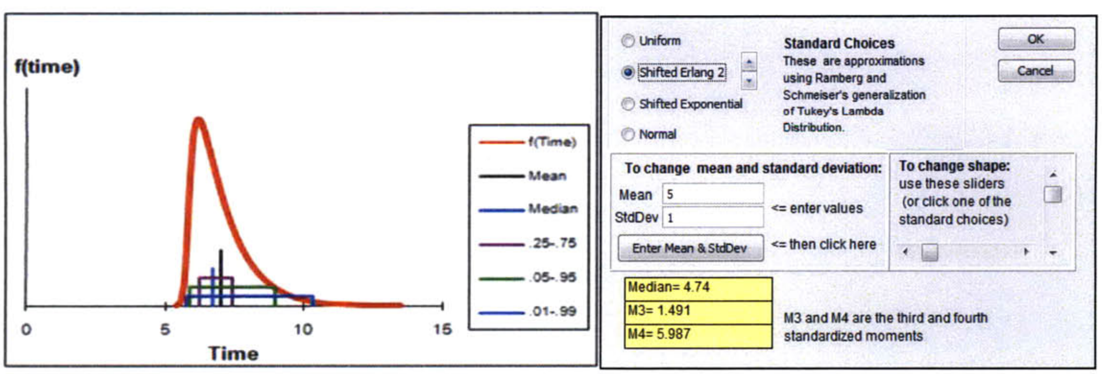

Figure 19: Cycle time distribution

Based on the previous cycle time records, it was concluded that all the work processes, including the package-shipping process, followed the above distribution due to the reasons such as parts waiting and special work requirements. The mean cycle times for current operation were captured as inputs for simulation, the standard deviations were set via experience; also, through interviewing engineers and assemblers, the ideal cycle time of each process was obtained. Table 8 lists all the cycle time inputs of the simulation.

Table 8: Production cycle time of workstations

Name	Abbreviation	Number of Station	Cycle time (day)		
			Current (mean)	St. dev.	Ideal
UES Subassembly Station	UES-sub	2	2	0.5	2
UES Frame Build Station	UES-frm-B	3	4.3	1	3
UES Test Station	UES-T	5	6.5	1	5
Prepare for Shipping	Prep4ship	1	1	0.2	0.5
Mod90 Build Station	Mod90-B	5	9.5	2	7.5
Mod70 Build Station	Mod70-B	5	5	1	5
Facility Build Station	Fac-B	3	4	1	4
Beamline Build Station	Beam-B	2	8	2	5.5
Terminal Build Station	Term-B	2	5.5	1	3.5
Mod90 Test Station	Mod90-T	2	4	1	3
Mod70 Test Station	Mod70-T	1	1.5	0.5	1
Facility Test Station	Fac-T	1	1.5	0.5	1
Beamline Test Station	Beam-T	1	2.5	0.5	2.5
Terminal Test Station	Term-T	1	3.5	0.5	3
Package & Shipping	P&S	4	4	1	4

6. RFID for miscellaneous parts checking

This chapter describes the solution to Problem 1 -- inefficient operation of miscellaneous parts. New part flow and new part operation procedures are put forward as recommendations for RFID implementation in VSEA in the future. Together with the solution, the result of cost and benefit analysis is discussed as a support for making the change.

6.1 New part flow process

Based on the changes that were proposed, a new part flow process was mapped to describe the new structure of internal logistics.

6.1.1 Quick Review of current miscellaneous part flow

As stated in 3.1.1, the miscellaneous parts of MC machine and HC machine follow different material flows, which results in much efficiency loss. The MC machine flow is the abnormal one in that parts are sent back and forth in the Shipping Area and the Air Shower, bringing extra work (de-trash, final assembly, wrapping) for the shipping area. The main reason of operating in this way is 1) the senior engineer now working in the shipping area was in charge of MC machine's final assembly and is familiar with that job; 2) the space in the clean room barely meet the needs of two miscellaneous flows. The current miscellaneous part flow is mapped (see Figure 20).

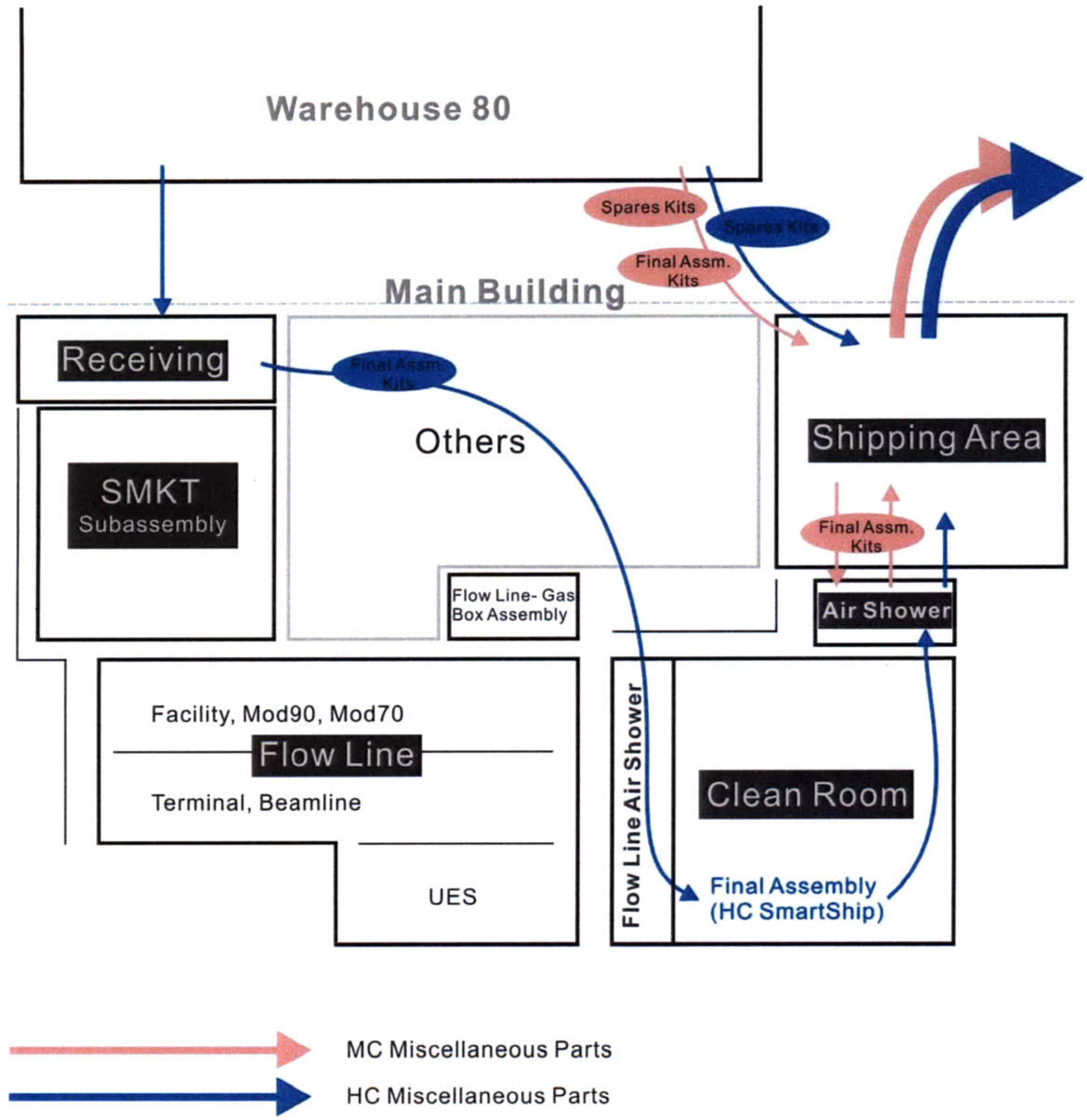

Figure 20: Current miscellaneous part flow

The two problems mentioned above were then further evaluated. For the first one, it was found that many workers currently working in the clean room are also good enough to take the responsibility of MC machine's final assembly; a qualified team is easy to be formed to do this job.

For the second problem, it was discovered that the parts that occupies spaces are mainly those in cages and bins that do not require final assembly work, but currently just need to be manually checked. Once RFID system is operated, these parts will be swiftly pass through the clean room and checked by RFID in the air shower, instead of staying in the clean room for one or two days. The potential concern is believed to be solvable by RFID.

6.1.2 New parts flow process

The redesign merges the MC flow and HC flow into one. The different operations of miscellaneous parts are reorganized to be finished in dedicated areas. Figure 21 suggests the new operation in detail. Spares and Specialties kits are directly sent to the Shipping Area for RFID checking and crating. The Final Assembly kits are split into two sections in the warehouse. Then they follow different operations. The one requiring extra assembly goes through more steps.

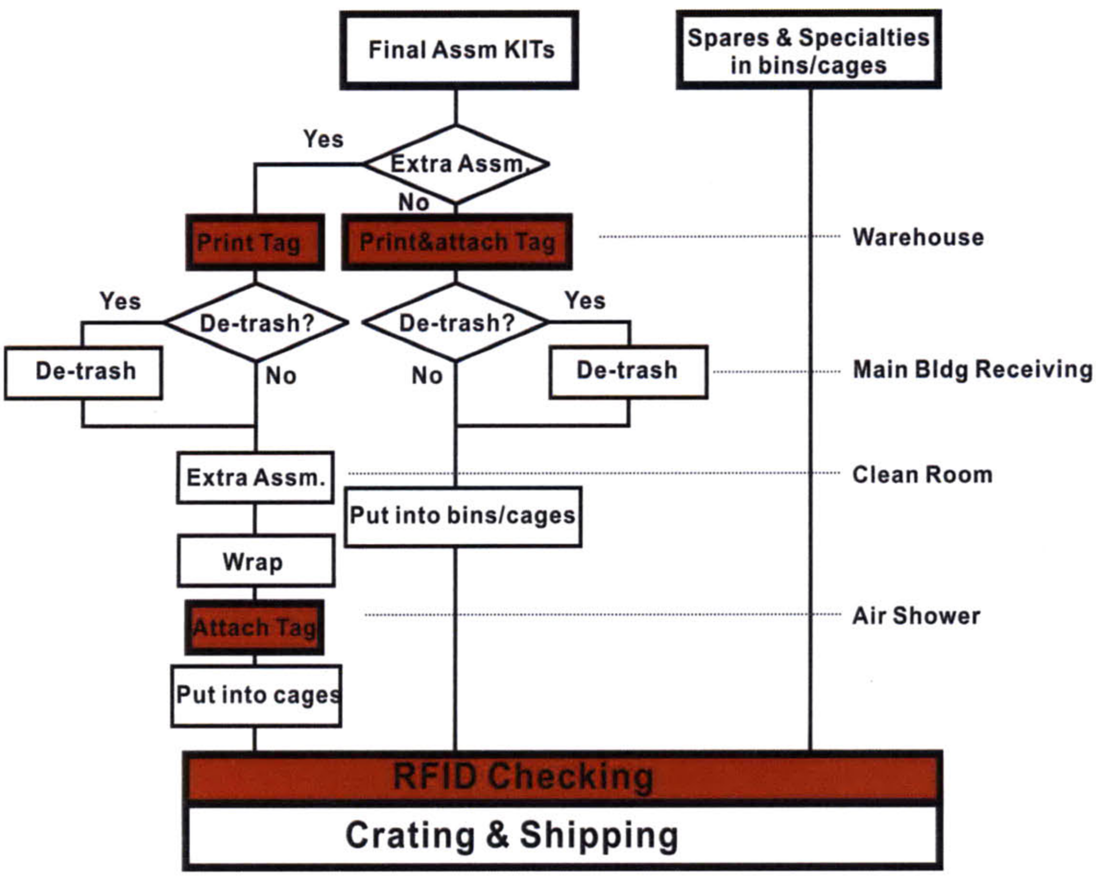

Figure 21: Revised flow of miscellaneous parts for combined MC and HC machine Production

Solution 1 (see Figure 22) suggests all the final assembly work, whether of MC machines or HC machines, be operated in the clean room. The warehouse is where the tags are prepared. Spare kits are entirely finished in the warehouse and go to the shipping area directly for RFID checking and crating. Final assembly kits go through the main building receiving area for de-trashing; some of them reach the clean room for extra assembly; the rest only pass the clean room and get checked in the air shower. All the final assembly kits are finally placed at the outgoing gate of air shower, ready for crating.

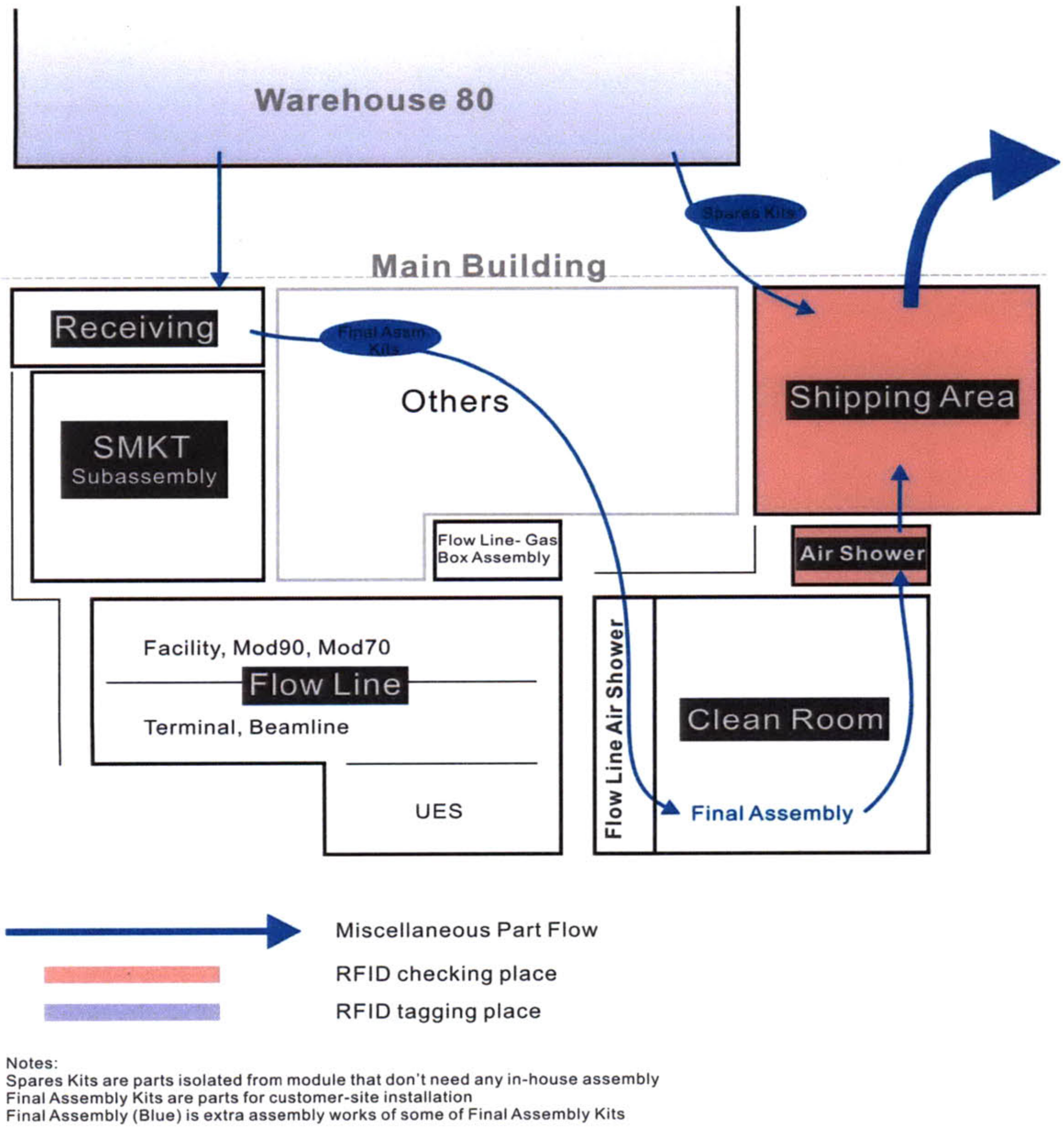

Figure 22: New flow map of solution 1 – All Final Assembly in the Clean Room

Solution 2, which is more revolutionary, suggests moving the final assembly work to the Supermarket instead of the clean room. The Supermarket already has the capability to provide subassemblies for different purpose; it is rational to integrate the extra final assemblies in SMKT. In this way, the Clean Room can focus on its Full-Build tasks. The dedicated operation is believed to lead to high efficiency.

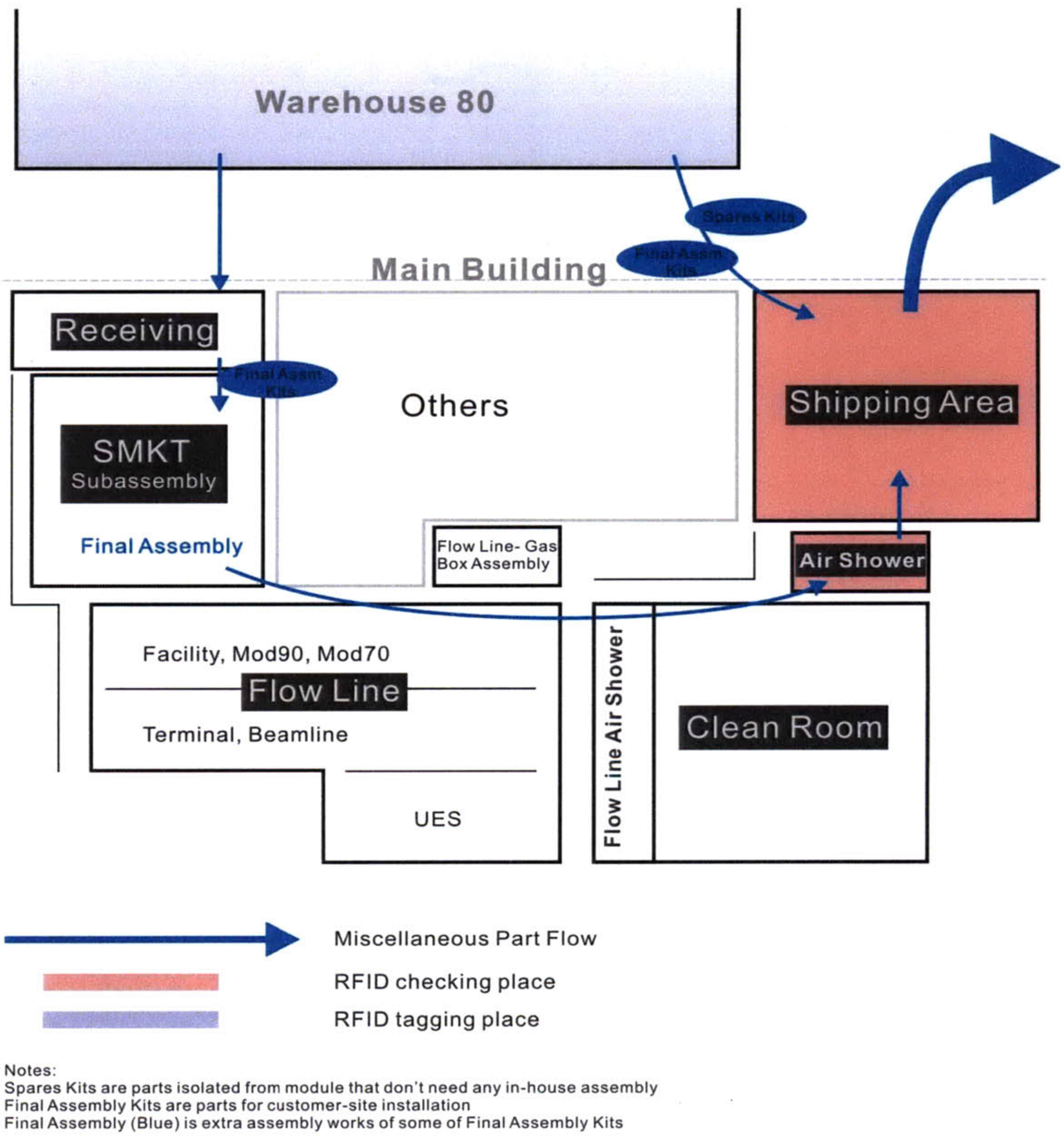

Figure 23: New flow map of solution 2 – All Final Assembly in the Supermarket

However, Solution 2 requires more floor space in SMKT to hold more tasks. Since the current SMKT is already crowded with space being highly utilized, reconfiguration of SMKT or enlarging the space is unrealistic in the near future. But for the purpose of efficiency, Solution 2 can be considered when the resources permit.

6.2 Tagging and checking procedures

The discussion in 5.2.1 yields the selection of the place to tag and check parts. The Warehouse Receiving desk and the Warehouse Sorting desk are selected to work together for RFID tagging. The added tagging procedure (together with the current receiving procedures) is listed in detail as follows:

Tagging procedures (tag registration):

1. At the Receiving desk, have a received package of parts on hand.
2. Remove the packing list and enter part information into SAP.
3. SAP obtains the parts information, the RFID printer prints tags associating with the parts in the package.
4. Attach receipts documentation to the package. (indicate inspection, testing , or direct stock)
5. Put the package (together with RFID tags and receipts documentation) on the conveyer, and send it to the Sorting desk.
6. At the Sorting desk, open the package.
7. Check the parts, and match the quantities with the receipts documentation.
8. Take out the glue cover of the RFID tag and attach it to the part. Since parts are with plastic bags, simply attach the tag to the plastic bags at a visible place.
9. Send the parts to stocking.

The checking processes take place both in the Air Shower and Shipping Area. The Air Shower RFID is prepared for Final Assembly kits that come from the clean room; the

Shipping Area RFID is used for checking the Spares kits directly coming from the Warehouse. The checking procedure is very easy as long as the equipment are established.

Checking procedures:

1. Have bins/cages of parts on hand, ready for checking.
2. Open the MultiReader software on the laptop, click "start".
3. Push the bin/cage through the RFID arch slowly.
4. Read the results on the laptop screen. If all the parts are sensed, continue to the next step; if parts are missed, report to the upstream department and pull the missing ones.
5. Crate the parts without extra checking.

6.3 Cost and Benefit Analysis

This implementation requires fixed investments including: 1) RFID equipment; 2) the corresponding racks, supports, cables and computers; 3) RFID-SAP central system. However, no extra manpower is needed since the added work can be accomplished by the existing workers.

The most direct savings comes from the reduction of labor hours in package-shipping. With the new part flow and RFID technology, the 10 hours spent on manually part checking in package-shipping can be eliminated, or at least considerably shortened with the RFID system. This eventually yields the cost saving of the company. (see Table 9)

Table 9: Cost saving in shipping with RFID checking (data modified for legal requirements)

Wage + overhead (shipping):	$60/hr
Time reduced in shipping:	10hrs/machine
Number of machines sold:	300machines/year (SmartShip)
Shipping labor savings:	**$180,000/year**

Wage + overhead (Warehouse):	$60/hr
Number of parts tagged:	200parts (phase I)
Time to tag a part:	30 sec/part (trained)
Time increased in WH:	100 min/machine
Number of machines sold:	300machines/year
Warehouse labor increase:	**$30,000/year**

Net saving in labor:	**$150,000/year**

Furthermore, although the new material flow is not able to bring direct saving of labor hour since it just transfers work to other areas, the setup time of doing multiple jobs in the shipping area can be removed (see Table 10). Also, the organized flow will bring more long-term benefits that cannot be quantified at the current stage.

Table 10: Cost saving with new miscellaneous part flow (data modified for legal requirements)

Wage + overhead (shipping):	$60/hr
Number of machines sold:	300 machines/year
De-trash setup	0.5 hr
Final Assembly setup	1 hr
Others (receive extra parts from dock; send parts back and forth to the air shower etc.)	1 hr
Net saving in labor:	**$45,000/year**

6.4 RFID experiment result of checking miscellaneous parts

The experiment of checking miscellaneous parts with RFID was operated in the real shipping environment. The checked item was a material cage full of bins and loose parts. The RFID arch was composed of two sided Farfield antennas and one Brickyard antenna (see Figure 24). When the material went through the arch, the tagged parts were sensed by the antennas in several seconds, and then shown on the laptop screen. The tag readability reaches almost 100%. The details of the experiments are described in Cyril Koniski's thesis [37].

Figure 24: Material cage and RFID arch

7. RFID for module part tracking

This chapter describes the solution to Problem 2 -- fraudulent claims and warranty costs of module parts. The module part flow almost remains the same, but the RFID tagging and checking processes are inserted at multiple stages; new part operation procedures are recommended in this chapter for RFID implementation. The result of cost and benefit analysis is discussed afterwards.

7.1 New part flow process

Since the phase II of the project aims at solving the problems of warranty tracking of shipped parts, it doesn't affect the internal material flow. Figure 25 displays the module flow with RFID tagging and checking processes being added.

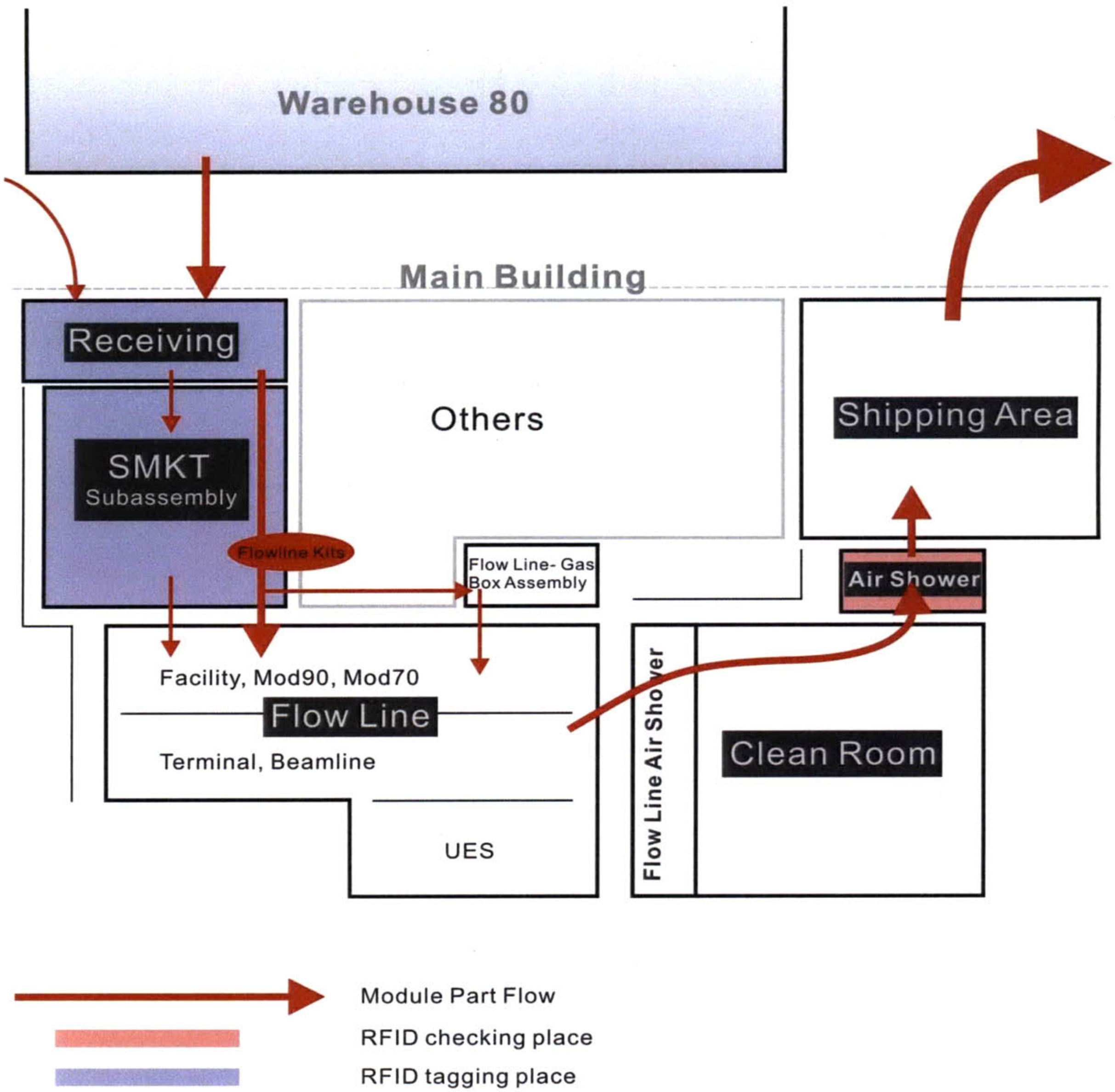

Figure 25: New flow map of Phase II – insert RFID Tagging in Warehouse, Main Building Receiving and Supermarket; insert RFID checking in Air Shower

7.2 Tagging and checking procedure

For module parts tracking, considering the multiple sources of incoming parts, the Warehouse, Main Building Receiving and SMKT are all selected to tag parts respectively, but following the same tagging procedures. A big difference from miscellaneous parts tagging is that the tags are attached directly on the surface of the parts instead of on the plastic bags. Because of the metal interference and customer requirements, each part/subassembly has a dedicated place to tag which is developed by the project team. Therefore, the operators need to follow special instructions to attach the tags.

Tagging procedures (tag registration):

1. Have a part on hand, with a sheet containing part number, PO number and Serial number.
2. Enter part number into SAP to search for the part.
3. Match the PO number on the screen with the one on the sheet.
4. Enter the Serial number.
5. Take a new RFID tag, and put it on the top of the Mini Guardrail RFID antenna.
6. Hear a beep to make sure the tag is registered, with tag ID being displayed on the screen.
7. Link the tag ID with the part information (part number, PO number and Serial Number) by a simple click.
8. Take out the glue cover of the tag and attach it to the part at the right place.
9. Put the part into a cart.
10. Send the part to the next stage.

The checking procedures will be operated in the Air Shower where the module gets wrapped and ready to crate. The checking process introduces a handheld RFID reader instead of an RFID arch for the purpose of sensing parts hiding deep inside the module, which are probably unreadable by the RFID arch whose signal cannot penetrate the metals. The handheld RFID reader is small enough to move around and sense the tags inside with higher probability.

Checking procedures:

1. Have an entire module in the Air Shower, ready for checking.
2. Activate the handheld reader, click “start”.

3. Stay close to the module, let the antenna face the module and wave the handheld reader from up to down and left to right; make sure the antenna senses all the module parts.
4. Walk around the module, and repeat 3.
5. Read the results on the screen of the handheld reader. If all the parts are sensed, continue to the next step; if parts are not sensed, do the tagging process.
6. Update the shipping date in the central system when modules are shipped out.

The information carried by each tag contains:

1. Serial number
2. Manufacturer
3. Warranty status
4. Material number
5. Material revision
6. Shipping date
7. Machine order number

7.3 Cost and Benefit Analysis

The cost savings comes from improving the operation of Serial number system. Serial numbers are given by suppliers to identify a specific part for warranty checking and maintenance with VSEA. Also, VSEA needs this Serial number to check warranties with its customer. Therefore, VSEA has to record these Serial numbers of the critical parts, as well as record the shipping date of the critical parts, in order to negotiate warranty issues both with suppliers and with customers.

Currently in VSEA, flow line workers record the Serial number of the critical module components manually, and then input them into SAP system, linking them with a machine order. Once a component fails in the test, a replaced one needs to be recorded again. That requires some time for the flow line worker.

Table 11: Cost saving in flow line with RFID checking (data modified for legal requirements)

Wage + overhead (flow line):	$60/hr
Time reduced on each recording:	3 min/part
Number of parts need to be recorded	100/machine
Number of machines sold:	300machines/year
Flow line labor savings:	**$90,000/year**

Wage + overhead (WH, Receiving, SMKT):	$60/hr
Time to tag a part:	30 sec/part (trained)
Number of parts tagged:	100parts
Number of machines sold:	300machines/year
labor increase:	**$15,000/year**

Net saving in labor:	**$75,000/year**

Moreover, in current operation, when a warranty problem occurs, operators in VSEA need to

1) Get the part Serial number from customer report,
2) Look for the machine that associates with this part,
3) Find the shipping date,
4) Check the hided information in the Serial number, and
5) Decide the warranty status and negotiate with either supplier or customer.

With RFID linked all the information, operators only need to: 1) get the part Serial number from customer report, 2) enter the Serial number into SAP and get everything on the computer, and 3) decide the warranty status and negotiate. The maintenance process is simplified in this way.

7.4 RFID experiment result of checking module parts

The experiment of checking miscellaneous parts with RFID was operated in the Air Shower. The checked items were one High Current Machine module and one Medium Current Machine module, while the checking equipment was an RFID arch together with a handheld reader. Around 20 tags were attached to the surfaces of different components which are exposed to a metal environment. The handheld reader turned out to be easily operated and achieve almost 100% read percentage. However, the RFID arch, although with more powerful antennas, cannot sense those tags hiding in the central of the module. The details of the experiments are described in Rui Jia's thesis [36].

8. RFID for flow line part tracking

Tracking parts in the flow line will enable a visible manufacturing line revealing all the parts status, which will bring great benefit to manufacturing management such as 1) knowing the exact inventory (Work-In-Process) level, 2) eliminating parts missing problems, 3) placing orders of parts at the right time, and so on. However, the implementation will require a sustained effort. However, since the concept is simple, this section puts forward a short proposal of RFID application in the flow line. Thereafter, much effort is put on simulation to analyze the system's performance of current status and ideal status (with RFID).

8.1 RFID proposal for flow line

The suggested RFID system functions when parts, whether kits or individual subassemblies enter the flow line (see Figure 26). All the parts in the flow line are supposed to have RFID identifications; parts statuses updated when they pass the RFID antennas, showing they are under process in the flow line.

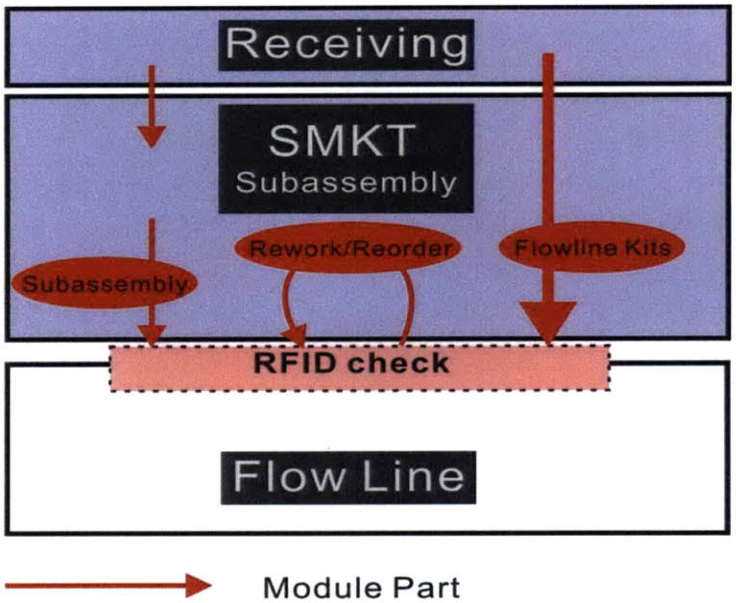

Figure 26: New parts flow to flow line

Materials entering in forms of kits are checked by an RFID arch, similar to the arch used for miscellaneous parts checking (see Chapter 6 and Cyril Koniski's thesis [36]); while individual parts, whether subassemblies or reworked/reordered parts, is supposed to be scanned by an RFID handheld reader.

The scanning provides information including 1) whether there is part missing for a kit, 2) which machine a part belongs to, 3) other information such as part number, quantity, version etc. The system will alarm if a kit is incomplete; the operator can then push the kit through the arch one more time to confirm the incompletion, and trigger the central system to pull that missing part. For an incoming individual part, the operator needs to scan it to match the information, and accept the part only if it is exactly the one prepared for his/her task. A logical model (see Figure 27) suggests how the system plays its role and what problems can be solved.

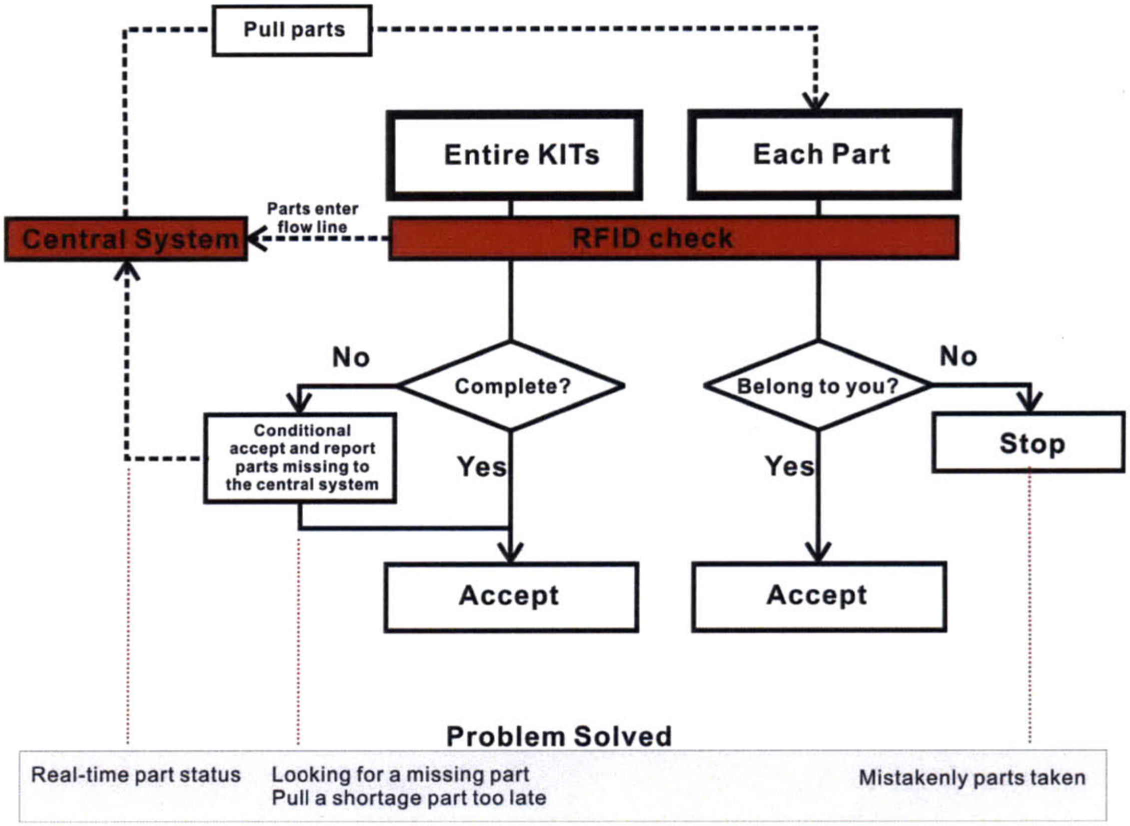

Figure 27: RFID logical model for flow line part tracking

The RFID in the flow line brings two significant changes to the operation. First, parts are exactly identified and dedicated, leading to visible and clear inventory level and Work-In-Process level. Parts in the flow line will not be taken by mistake and unrecognizable parts can find their way back to the process by RFID scanning. Second, missing parts or shortages are found and reported at the very beginning, which enables the material preparation department to have enough time to respond and fill the shortage. Otherwise, operators sometimes only find missing parts when they need them in assembly, which delays the work.

Therefore, the RFID system for flow line parts tracking has the potential to solve the existing problems in operation and shorten the cycle time of the processes to an ideal level. The following sections, 8.2 and 8.3, analyze the current operation and the ideal operation with RFID respectively by simulation. The improvements and benefits is concluded through comparison of the two systems.

8.2 Simulation result of current system

As stated in Chapter 5, the software CellSim was applied to simulate the entire manufacturing system. The annual demand estimation in Table 7 and the mean cycle time as well as the standard deviation in Table 8 were input to run the simulation of current system.

8.2.1 Results

The result indicates a healthy manufacturing system in general. The system could meet the demand quite well, with almost no accumulation of orders on the upstream production planning stage. During a one-year cycle, around 214 machines were built and shipped, which was consistent with the reality. The simulation was run three times. The breakdown of the finished products is displayed in Figure 28.

Machine Finished	HC	MC
1st Quarter	40	16
2nd Quarter	37	15
3rd Quarter	37	17
4th Quarter	38	17
Total	152	65

Machine Finished	HC	MC
1st Quarter	36	17
2nd Quarter	38	15
3rd Quarter	38	16
4th Quarter	37	16
Total	149	64

Machine Finished	HC	MC
1st Quarter	37	15
2nd Quarter	36	17
3rd Quarter	38	16
4th Quarter	38	14
Total	149	62

Figure 28: Machine produced in three runs of simulation for current operation

The majority of the workstations ran at their normal status throughout the simulation. The inventory level in the processes was kept at a low level. However, some of the workstations such as "Mod70" and "Fac" were always starving, which indicates low utilization. A snapshot of the running model is captured in Figure 28.

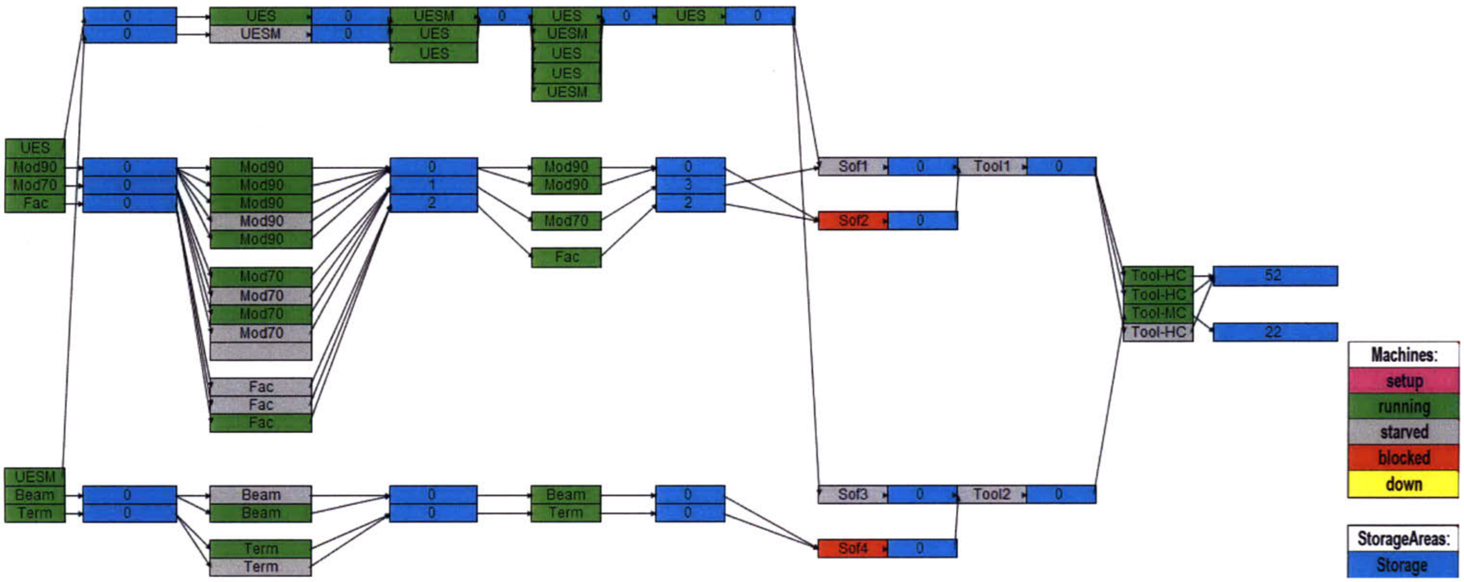

Figure 29: A snapshot of the running manufacturing system

However, the system was not perfect in that the three main branches of assembly were not well balanced. The UES module line (see the upper line in Figure 29) was the busiest line compared to the HC modules line and the MC modules line (see the middle and lower lines in Figure 29). The workstations in the UES line were highly utilized. The UES-frame-build processes ran almost with full utilization; the UES-Test stations were also busy with around 88% utilization. In the HC modules line, the "90 module" branch was highly occupied with over 95% utilization; the other two branches, "70 module" and "Facility", were only 60% utilized. The MC module line is the fastest one of the three main branches.

Table 12: Utilization of the main workstations

Workstation	Utilization	Workstation	Utilization	Workstation	Utilization
UES-sub-B1	0.71	ModHC90-1	0.93	Mod70T	0.71
UESM-sub-B1	0.66	ModHC90-2	0.93	ModFac-1	0.79
UES-frm-B1	0.97	ModHC90-3	0.92	ModFac-2	0.68
UES-frm-B2	0.96	ModHC90-4	0.87	ModFac-3	0.45
UES-frm-B3	0.99	ModHC90-5	0.86	FacT	0.73
UES-T1	0.90	Mod90T1	0.97	ModBeam-1	0.82
UES-T2	0.92	Mod90T2	0.95	ModBeam-2	0.87

UES-T3	0.89	ModHC70-1	0.78	BeamT	0.54
UES-T4	0.86	ModHC70-2	0.75	ModTerm-1	0.66
UES-T5	0.80	ModHC70-3	0.60	ModTerm-2	0.45
Pre4Ship	0.68	ModHC70-4	0.26	TermT	0.73
		ModHC70-5	0.02		

8.2.2 Discussion

The TAKT time, which reveals the production rate of each workstation and indicates the bottleneck, is listed in Table 13. The UES module line is the bottleneck of the entire system as revealed by the simulation. Although the UES line produces UES module at the highest rate – 0.68 modules per day, it is not fast enough to easily serve both the HC machines and MC machines. The longest process, UES-frame-build, has a long TAKT time equal to the requirement, mainly due to the long cycle time of the process and the lack of workstations, which means it barely meets the demand. If the demand increases but nothing changes with the UES-frame-build, the extra orders will be accumulated upstream, leading to problems of insufficient capacity.

Table 13: TAKT time of the main workstations

		Cycle time	Celles	TAKT time	Required TAKT time
UES	UES-sub-B1	2	2	1	1.44 (assuming the annual machine demand is 216)
	UES-frm-B1	4.3	3	1.43	
	UES-T	6.5	5	1.3	
	Pre4Ship	1.2	1	1.2	
HC	ModHC90	9.5	5	1.9	2.07 (assuming the annual HC machine demand is 151)
	ModHC70	5	5	1.2	
	ModFac	4	3	1.33	
	Mod90T	4	2	2	
	Mod70T	1.5	1	1.5	
	FacT	1.5	1	1.5	
MC	ModBeam1	8	2	4	4.8 assuming the annual MC machine demand is 65)
	ModTerm-1	5.5	2	2.75	
	BeamT	2.5	1	2.5	
	TermT	3.5	1	3.5	

The long TAKT time of the UES line also causes the loss of utilization in two other main lines, since modules of each machine are laid down at the same time and shipped as a whole. For one machine, the finished HC/MC module must wait for its corresponding UES module, no matter how early they are finished. From the data in Table 12, it is noticed that some of the workstations for module building are only 40% to 60% utilized, which is typically a low usage. The average utilization of all the workstations is around 75%, not including the loss of time waiting for missing parts. If that loss of time is included, the utilization will be lower.

However, labor sometimes is shifted to other tasks in other workstations. The workstations for module building are just rectangular areas for locating a machine, with tool carts and material carts aside if module is under building. However, the assemblers are cross-trained and flexible. There are situations where some of the workstations are empty, whereas the assemblers have been shifted from this workstation to other areas to help. Therefore, the loss comes only from the low utilization of the workstation; while the labor is comparatively highly utilized. But in general, there's much room for improvement of the current manufacturing system.

8.3 Simulation result of an ideal system

As stated in section 8.1, the RFID system can help the flow line to solve the parts missing and parts shortage problems, achieving an ideal production performance without adding more testing equipment or labor. The new simulations applied the "ideal cycle time" in Table 8 as inputs, but followed two different assumptions. For case 1, the system were kept busy with highest utilization, so the capacity increased in the new simulation; for case 2, the demand was kept to be 216 as before, then some workstations were idle and inventories were reduced. Both of the two cases were simulated, leading to different but in both cases better results.

8.3.1 Results of case 1: Higher Demand

The simulation ran with a new demand of 297 machines per year as input, and the result still indicates a healthy manufacturing system in general. The simulation ran three times. During a one-year cycle, 295 machines are built and shipped in average. The breakdown of the finished products is displayed in Figure 30.

Machine Finished	HC	MC	Machine Finished	HC	MC	Machine Finished	HC	MC
1st Quarter	49	19	1st Quarter	49	21	1st Quarter	51	23
2nd Quarter	49	21	2nd Quarter	50	23	2nd Quarter	51	19
3rd Quarter	49	24	3rd Quarter	52	18	3rd Quarter	53	22
4th Quarter	52	18	4th Quarter	51	21	4th Quarter	53	21
Total	199	82	Total	202	83	Total	208	85

Figure 30: Machine produced in three runs of simulation for ideal operation

The workstations ran well throughout the simulation. Compared to the current system, there were much fewer starving situations taking place in the new system. A snapshot of the running model (Figure 31) is captured.

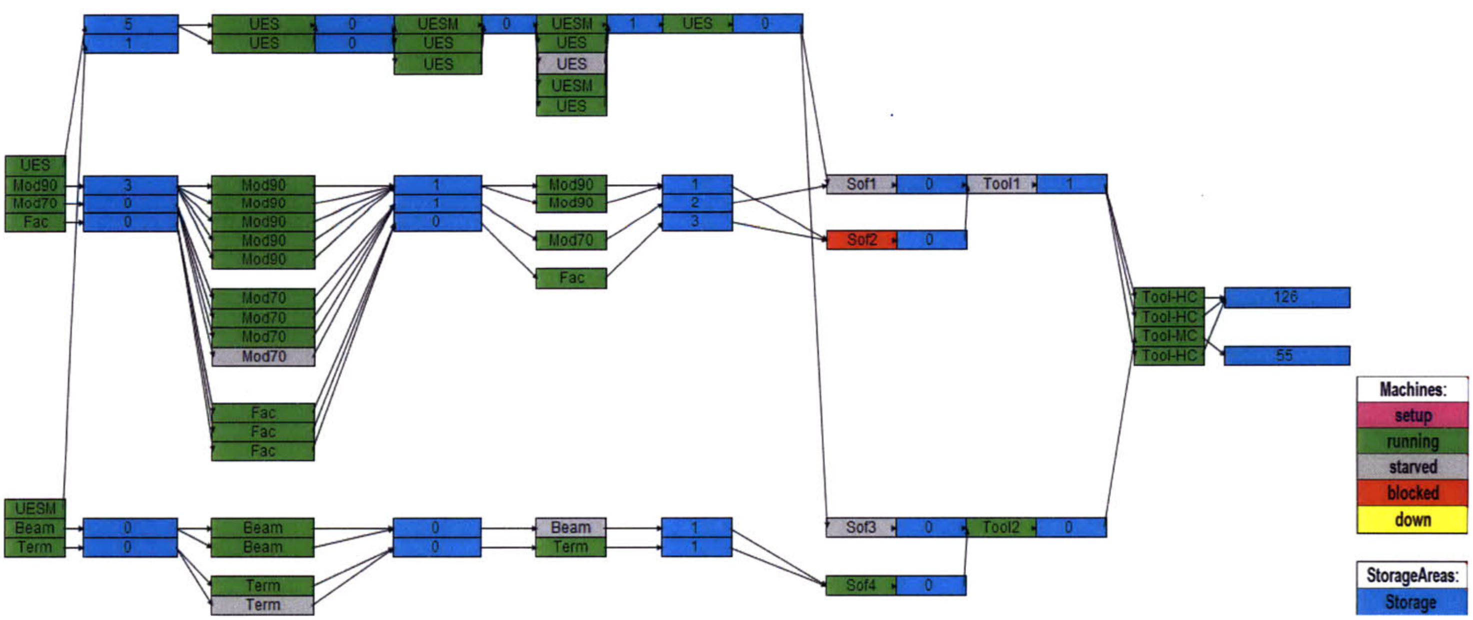

Figure 31: A snapshot of the running manufacturing system for 297 annual machine demands

The utilization of the workstations increases to 85% on average, over 10% higher than the current system. Table 14 lists the utilization of the main workstations. The improvement mainly comes from the reduction of the bottlenecks' cycle time. The TAKT time of the sequential processes in one line are close to each other; the TAKT time of different lines are close to the capacity requirements. Therefore, different production lines and workstations are better balanced, yielding better utilization of the workstations (see Table 15).

Table 14: Utilization of the main workstations

Workstation	Utilization	Workstation	Utilization	Workstation	Utilization
UES-sub-B1	0.93	ModHC90-1	0.93	Mod70T	0.83
UESM-sub-B1	0.96	ModHC90-2	0.97	ModFac-1	0.90
UES-frm-B1	0.93	ModHC90-3	0.93	ModFac-2	0.86
UES-frm-B2	0.92	ModHC90-4	0.93	ModFac-3	0.86
UES-frm-B3	0.88	ModHC90-5	0.91	FacT	0.77
UES-T1	0.95	Mod90T1	1.00	ModBeam-1	0.79
UES-T2	0.94	Mod90T2	1.00	ModBeam-2	0.72
UES-T3	0.92	ModHC70-1	0.88	BeamT	0.87
UES-T4	0.91	ModHC70-2	0.85	ModTerm-1	0.73
UES-T5	0.89	ModHC70-3	0.80	ModTerm-2	0.25
Pre4Ship	0.45	ModHC70-4	0.71	TermT	0.85

Table 15: New TAKT time of the main workstations

		Cycle time	Celles	TAKT time	Required TAKT time
UES	UES-sub-B1	2	2	1	1.05 (assuming the annual machine demand is 300)
	UES-frm-B1	3	3	1	
	UES-T1	5	5	1	
	Pre4Ship	0.5	1	0.5	
HC	ModHC90-1	7	5	1.4	1.5 (assuming the annual HC machine demand is 210)
	ModHC70-1	5	4	1.25	
	ModFac-1	4	3	1.33	
	Mod90T1	3	2	1.5	
	Mod70T	1.3	1	1.3	
	FacT	1.3	1	1.3	
MC	ModBeam1	5.5	2	2.75	3.5

	ModTerm-1	3.5	2	1.75	(assuming the annual MC machine demand is 90)
	BeamT	2.5	1	2.5	
	TermT	3	1	3	

8.3.2 Results of case 2: Current Demand

The simulation of case 2 kept the original demand of 216 machines per year as input. Since the system was definitely much faster, all the machine orders were filled easily. From the animation of simulation, it is concluded that many of the workstations were starving most of the time. The snapshot of the running model (see Figure 8.3) shows many cells in grey, representing idle status at that time. The number of machines in the line (Work In Process) were also reduced.

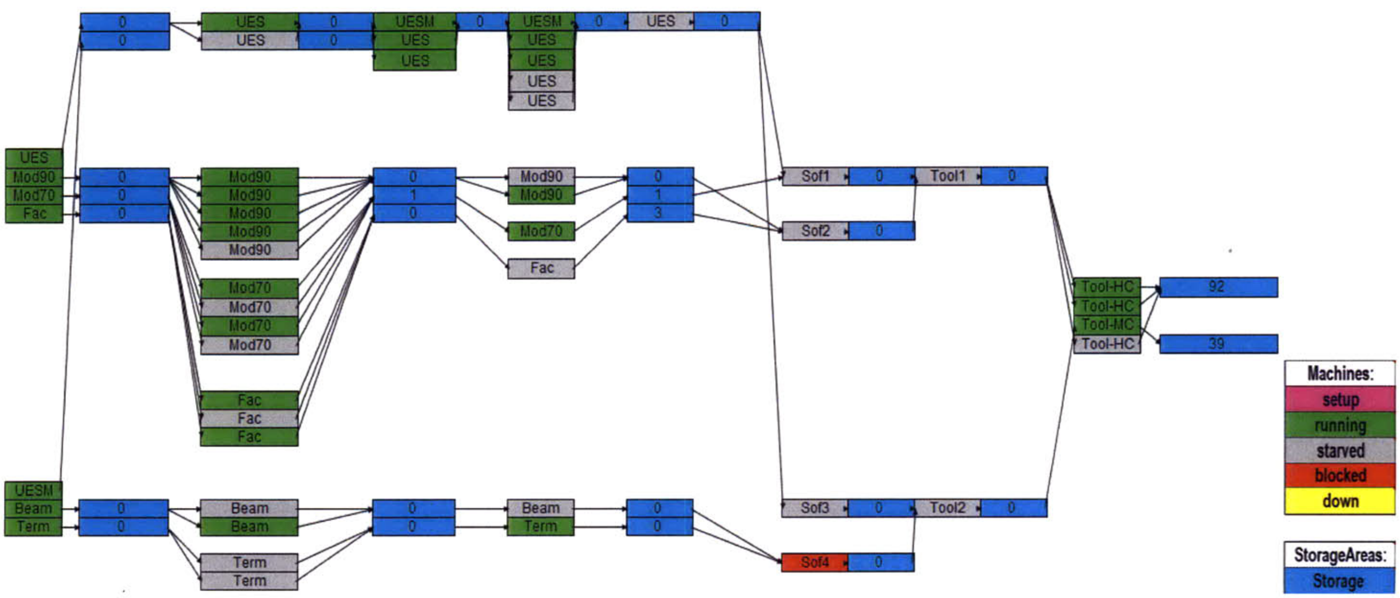

Figure 32: A snapshot of the running manufacturing system for 216 annual machine demands

The low utilization of some of the workstations shows the redundant capacity with the certain demands. Some workstations can be removed to save the operation cost. According to the recalculation of the TAKT time (see Table 16), 5 workstations can be removed without affecting digesting the demands.

Table 16: New TAKT time of the main workstations

		Cycle time	Celles	TAKT time	Required TAKT time
UES	UES-sub-B1	2	2	1	1.44 (assuming the annual machine demand is 300)
	UES-frm-B1	3	3	1	
	UES-T1	5	4	1.25	
	Pre4Ship	0.5	1	0.5	
HC	ModHC90-1	7	4	1.75	2.07 (assuming the annual HC machine demand is 210)
	ModHC70-1	5	3	1.67	
	ModFac-1	4	2	2	
	Mod90T1	3	2	1.5	
	Mod70T	1.3	1	1.3	
	FacT	1.3	1	1.3	
MC	ModBeam1	5.5	2	2.75	4.8 (assuming the annual MC machine demand is 90)
	ModTerm-1	3.5	1	3.5	
	BeamT	2.5	1	2.5	
	TermT	3	1	3	

8.4 Cost and Benefit Analysis

The new system provided increased production capacity which would enable VSEA to produce up to 300 machines per year without adding equipment and labor. Given the current limit of 216 machines per year, the capacity is raised by 37.5%.

On the other hand, if the demand remains at a low level, VSEA can save cost by reducing floor space and lowing Work-In-Process level. As discussed in section 8.3.2, 5 work bays can be removed or converted for other usage, the land resource saved in this way. Also, the new system only has 8 to 9 Work-In-Process machines, lower than the current system, which holds 11 to 12. The Work-In-Process, which is also a form of inventory, is then reduced by 3 entire machines, leading to millions of cost saving in inventory.

9. Conclusion and Future work

9.1 Conclusion

Reflecting on the results of the entire project, an RFID system is worth to be implemented in VSEA's manufacturing system to help achieve better performance. The RFID technology were proved to be workable and reliable in VSEA's environment; the experiments delivered good checking result with 100% read percentage, which established the foundation of implementation. The new tagging/checking processes as well as the redesigned material flow, already evaluated with the manufacturing managers, turned out to be feasible and applicable. The cost/benefit analysis, together with the production line simulation, suggested the potential to improve VSEA's manufacturing system with RFID.

Particularly, this thesis aims at operation analysis and process redesign of VSEA's manufacturing system. The three main operational problems that VSEA encounters are discussed. The current state of each process is captured and analyzed to prepare for potential change. Three solutions (Phases), which are based on the successful experiments of RFID technology, are proposed to tackle each of the problems.

Phase I: RFID for miscellaneous parts checking

An RFID system is proposed to improve the checking system by replacing the manual checking process with RFID automatic sensing. It is also suggested to integrate the two miscellaneous flows into one to better serve the RFID implementation and smooth the material chain. The total labor cost saving of Phase I was estimated to be $195,000 annually.

Phase II: RFID for module tracking (high value parts)

Identifying the critical module components with RFID tags were proved to be helpful to check their warranty status. RFID expedites the in-house warranty preparing process, and also simplifies the warranty checking process, leading to labor savings of $75,000 annually.

Phase III: RFID for flow line part tracking

RFID implementation in the flow line were proposed as a long-term plan, which involves tagging (identifying) almost all the parts in VSEA. The simulation suggested RFID can help the flow line to significantly reduce the cycle time of most processes, yielding the increase of production capacity by 37.5%, or millions of saving in inventory annually.

9.2 Future work

The future work of the project involves more real practice to implement an RFID system in VSEA. With the proposal being put forward and evaluated to be feasible and helpful, actions will be taken to launch a test run. The full-scale implementation will be the ultimate goal if the system is proved to be beneficial.

9.2.1 SAP integration

The current biggest hurdle is to link the RFID system with the company's SAP database. Since information from RFID checking is supposed to be matched with the parts information in SAP all the while, there is a need to develop an RFID-SAP integration system to realize full automation. However, Varian's RFID functionality in SAP is frozen until next year. To expedite the RFID implementation, the company is planning to develop an independent RFID-Material BOM system, which involves programming work and interface design.

9.2.2 Equipment setup at each site

As several stages were selected to add either tagging procedures or checking procedures, equipment setup at these sites will be a critical step for implementation. Particularly for the RFID arch design, a dedicated frame needs to be designed to fix the antennas as well as the reader. Floor layout needs to be modified to locate an RFID arch and corresponding computers. Since parts are supposed to pass the RFID arch, the route of parts flow at each stage should be reconsidered as well.

9.2.3 Operator training

With the setting of the hardware, operators need to be trained according to the tagging and checking procedures suggested in Chapter 6 and Chapter 7. The operators involved in Phase II – module parts tagging and checking, need to follow special instructions to tag parts at the right place. All the employees working in the manufacturing system are required to learn how to read a part with RFID and check information of that part on computer, for the purpose of being able to "read a part" any time.

9.2.4 Performance record

Once the test run of RFID system is launched, it is necessary to record data such as new cycle time of the processes, labor hours, part missing problems etc. The operators should be also interviewed about the feeling of using RFID system. The data from test run should be carefully analyzed to serve the full-scale implementation.

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Appendix

Production Time Line of Universal End Station (UES) module

Tool	Mod L/D	Ready to test	Finish	Ship
1	2/11	2/26	3/5	3/20
2	2/18	3/1	3/5	3/11
3	2/17	3/3	3/8	3/25
4	2/19	3/2	3/8	3/15
5	2/14	3/1	3/11	3/13
6	2/25	3/5	3/11	3/15
7	2/24	3/6	3/13	3/16
8	2/22	3/5	3/14	3/15
9	3/3	3/11	3/16	3/19
10	2/25	3/12	3/17	3/19
11	2/26	3/11	3/18	3/26
12	3/2	3/14	3/19	3/29
13	3/7	3/16	3/23	3/24
14	3/9	3/18	3/22	3/30
15	3/12	3/19	3/25	3/31
16	3/13	3/21	3/29	3/30
17	3/16	3/24	3/29	4/1
18	2/22	3/24	3/30	5/14
19	3/12	3/26	3/31	4/9
20	3/15	3/26	4/1	4/9
21	3/18	3/29	4/2	4/6
22	3/19	3/29	4/4	4/10
23	3/22	3/30	4/6	4/9
24	3/25	3/31	4/7	4/12
25	3/23	4/2	4/8	4/16
26	3/29	4/5	4/9	4/20
27	4/2	4/5	4/10	4/14

28	3/26	4/6	4/13	4/16
29	3/27	4/9	4/15	4/26
30	3/29	4/9	4/15	4/16
31	4/3	4/10	4/15	4/20
32	4/8	4/15	4/20	4/20
33	4/1	4/9	4/21	5/12
34	4/6	4/17	4/22	5/24
35	4/6	4/16	4/22	4/30
36	4/10	4/20	4/26	5/4
37	4/10	4/19	4/26	5/17
38	4/13	4/21	4/27	4/30
39	4/12	4/22	4/29	5/3
40	4/13	4/23	4/29	5/20
41	4/19	4/26	5/1	5/5
42	4/13	4/13	5/1	5/4
43	4/16	4/28	5/5	5/7
44	4/23	5/1	5/7	5/7
45	4/15	4/28	5/7	5/14
46	4/20	5/5	5/10	6/24
47	4/21	5/4	5/11	6/15
48	4/9	5/7	5/13	6/4
49	4/22	5/6	5/14	5/14
50	4/30	5/8	5/16	5/20
51	5/3	5/12	5/17	6/9
52	4/29	5/11	5/19	5/27
53	5/7	5/14	5/19	5/25
54	5/8	5/15	5/19	5/28
55	5/8	5/17	5/22	6/1
56	4/28	5/14	5/24	6/21

57	5/11	5/19	5/25	6/11
58	5/12	5/21	5/26	6/4
59	5/14	5/24	5/28	6/4
60	5/14	5/25	5/30	6/15
61	5/18	5/26	5/31	6/15
62	5/20	5/28	6/4	6/18
63	5/12	5/28	6/5	7/7
64	5/23	6/1	6/7	6/17
65	5/20	6/2	6/10	6/21
66	5/24	6/4	6/13	7/28
67	5/26	6/8	6/14	6/25
68	5/19	6/5	6/15	7/30
69	5/28	6/5	6/15	6/21
70	5/27	6/9	6/17	6/21
71	5/28	6/9	6/17	6/23
72	5/29	6/10	6/17	6/25
73	6/2	6/16	6/20	6/28
74	6/9	6/16	6/22	6/25
75	5/26	6/18	6/24	7/6
76	6/11	6/17	6/24	7/9
77	6/11	6/18	6/24	6/30
78	6/18	6/22	6/29	7/7
79	6/16	6/23	6/29	8/9
80	6/11	6/25	6/29	7/30
81	6/10	6/25	7/2	8/10
82	6/21	7/2	7/6	7/16
83	6/20	6/30	7/6	10/19
84	6/21	7/1	7/7	8/23
85	6/26	7/2	7/9	7/12

86	7/2	7/7	7/11	7/12
87	6/29	7/7	7/13	7/30
88	6/24	7/6	7/14	8/1
89	7/2	7/14	7/18	7/19
90	6/28		7/18	7/23