Materials Lead Time Reduction in a Semiconductor Equipment Manufacturing Plant: Warehouse Design and Layout

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Bachelor of Science in Mechanical Engineering
Boston University, 2012

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

Master of Engineering in Manufacturing

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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ABSTRACT

The warehouse layout and operations of a semiconductor tool manufacturer were studied with the objective of reducing the lead time for parts ordered from the warehouse to 8 hours. Current order fulfillment operations were studied and interviews with involved personnel were conducted. Additionally, data was extracted and analyzed from the company's SAP Extended Warehouse Management database to analyze the past performance of the warehouse operations. Three main areas for improvements were analyzed and recommendations were made regarding each area.

First, it is recommended that a kit of parts ordered should be sent immediately the constituent parts are consolidated and the kit is completed. This saves an average of 6 hours that parts in a complete kit wait for other kits to be completed before being sent out. Second, the picking aisles of the warehouse should be cleared so that parts in storage locations are easily accessed for picking and no time is wasted on clearing a path to pick a part. This leads to an average time saving of 1.2 hours per day on the time parts are delivered. Third, the receiving and sorting areas in the warehouse should be combined together. This frees up storage space for excess bulk material which block picking aisles. These recommendations are to be combined with other material flow improvements. It was determined that the goal of 8 hours lead time is unrealistic. However, calculations suggest that lead time will be reduced to 16 hours.

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Acknowledgements

I would like to thank everyone for their support in making this project possible. I would like to thank our thesis advisor Dr. Stephen C. Graves for his guidance and swift feedback when needed. I would also like to thank Prof. David Hardt, Dr. Brian Anthony, and Jose Pacheco for their mentorship over the course of the MEng Manufacturing program at MIT. Thanks also to Jennifer Craig for her insightful feedback and guidance in writing this thesis.

I would also like to thank Daniel Martin and Scott Sherbondy of Varian Semiconductor Equipment – Applied Materials for giving us the opportunity to gain valuable experience in industry through this project. Thanks also to Ron Dognazzi, Mark Goodhue, John Davis, Phil Hobbs, Robbie Roberts, and Guy Peritore for the knowledge and experience shared. Thanks also to Vinny, Mark, Tom LeBlanc, Bob Cook, Bruce, and all the other warehouse and production employees for their patience in in answering our questions.

Thanks also to my teammates Ryan Surveski and Prachyathit Kanburapa for a wonderful time spent. This project was more than just work. We got to know ourselves better, and helped one another in areas where we lacked.

Finally, I would like to thank my family for all the support shown in bringing me to where I am now. Thanks to my dad for giving me the opportunity to come to the US for college. Daddy, I wish you were here to enjoy the success of what you started. Mommy, thank you for not holding back, and letting me go to college far away from home. Thanks to my aunt and uncle for welcoming me to Boston as a son in the family. Thanks to my friends here at MIT and the rest of the MEng Manufacturing cohort. Snegdha Gupta, thanks for all the troubles, and the good times.

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1. Introduction

At the Varian Semiconductor Equipment Associates division of Applied Materials, hundreds of parts needed for manufacturing are sent from the warehouses to the production floor every day. This process usually takes in excess of twenty-four hours. This is an issue because any changes during the lead time means those parts will be sent back, creating more work. This thesis describes work done on warehouse layout, a part of the overall effort to reduce the lead-time of parts delivery within the company.

The purpose of this section is to give a brief background of the semiconductor industry. Specifically it will highlight the role that Applied Materials and the Varian Semiconductor Equipment Associates business unit play within the semiconductor industry. This section will also describe the need for a shorter lead-time at Varian Semiconductor Equipment Associates and how the research to address it was divided.

1.1 Semiconductor Tooling Industry

Semiconductors are essential components of phones, computers, cars, televisions, and a wide range of electronic devices. A few large semiconductor manufacturers primarily satisfy this large market. This is because the tooling cost to setup a semiconductor fabrication requires a huge capital expense. Semiconductor manufacturing requires eighteen major steps; each need tooling. Many of these machines cost over $1 million [1]. The companies who are large enough to do this include Intel, TSMC (Taiwan Semiconductor Manufacturing Corporation), Analog Devices, Samsung, Global Foundries, IBM, and Toshiba [2].

In 2008 and the years since, the economy has hurt many industries including electronics and semiconductors. Although they have somewhat bounced back now, this did slow the purchasing of semiconductor fabrication equipment. This has slowed down production for companies like Applied Materials to below their previous production capacity.

1.2 Applied Materials

Applied Materials is a company headquartered in Santa Clara, CA. It is a manufacturer of many items, mostly for the electronics industry. These include solar, glass, LCD display, and semiconductor products [3].

As of October 2012, Applied Materials had over 14,500 employees. In fiscal year 2012, Applied Materials had $8.7 billion revenue and $109 million in profit [3].

Applied Materials has acquired many companies since it was founded in 1967. In May of 2011, they announced that they would buy Varian Semiconductor Equipment Associates for $4.9 billion [4]. Varian Semiconductor Equipment Associates was then acquired on November 10, 2011 for about $4.2 billion [5].

1.2.1 Varian Semiconductor Equipment Associates

Varian Semiconductor Equipment Associates manufactures the equipment for the ion implantation step of semiconductor manufacturing and they sell to many of the large semiconductor manufacturing companies.

Varian Semiconductor Equipment Associates was one of three public companies formed as a result of the division of its parent company, Varian Associates, in 1999. Varian Associates, which was formed in 1948, entered the ion implantation market with its acquisition of Extrion Corporation in 1975. This company later became Varian Semiconductor Equipment Associates. In 2010, Varian Semiconductor Equipment Associates' revenue was over $800 million with profits of over $150 million [6].

Varian Semiconductor Equipment Associates (henceforth referred to as Varian) is now part of the Silicon Systems Group at Applied Materials. This group makes machines that perform many of the stages of semiconductor manufacturing [1].

1.2.2 Ion Implantation

Ion implantation machines are often used for doping of semiconductors. Doping is a major step in the manufacturing of semiconductors. During the ion implantation, the machine accelerates ions through an electric field. The ions will then hit a solid, in this case, the wafer. This impact changes the wafer chemically and physically. In the doping process, the manufacturer wants to add the ion that is being accelerated to the wafer [7].

Figure 1-1 shows an ion implanter made by the Silicon Systems Group at Applied Materials. Varian makes and tests these machines, then delivers them over to the customer.

Figure 1-1: Applied Materials ion implanter [8]

Figure 1-2 shows wafers being processed inside the ion implanter. Customers of Varian will perform this operation to the wafers as well as many others.

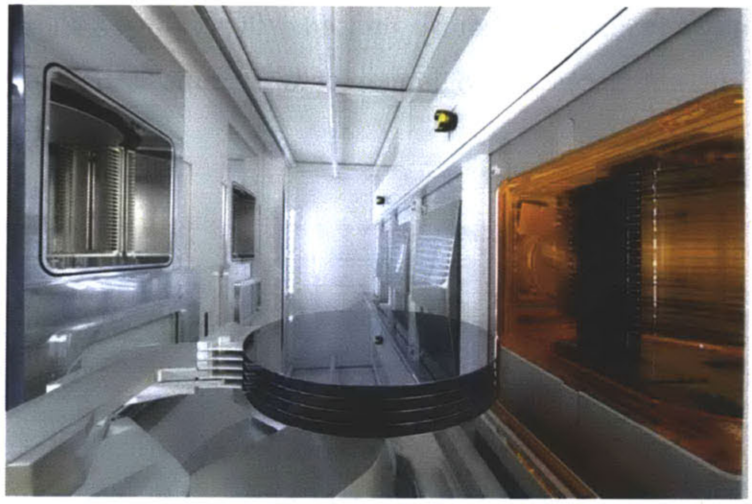

Figure 1-2: Wafers inside an ion implanter [8]

1.2.3 Product Offerings

Varian offers ion implanters in four main categories. This depends on the energy intensity and level of doping the product delivers [1]. These categories are High Current (HC), Medium Current (MC), High Energy, and Ultra High Dose (PLAD). Varian offers a range of high-mix low volume products. These products are produced in low volume, but are highly customized. This leads to a high number of stock keeping units (SKUs) needed by Varian.

1.3 The Need

Ion implantation machines have many parts and are highly customizable to what the customer needs. This results in Applied Materials keeping many SKUs. Just the Varian division has over 20,000 SKUs. At the Varian division, most of these parts are kept in three warehouses (building 5, 70, and 80) with the majority of them kept in building 80.

The production floor for ion implanters is located in building 35, about a half-mile from building 80. Hundreds of parts are moved every day from building 80 to building 35. From the time a part is ordered in building 35 to the time it is received, there is currently a twenty-four hour promised delivery time. A shorter deliver time is preferred, but not necessary. A longer delivery time is bad and slows down production.

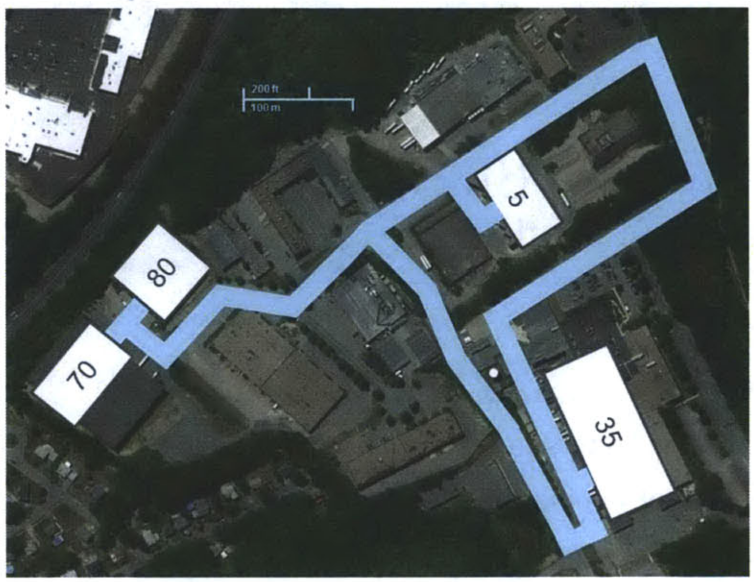

Figure 1-3: Map with locations of buildings

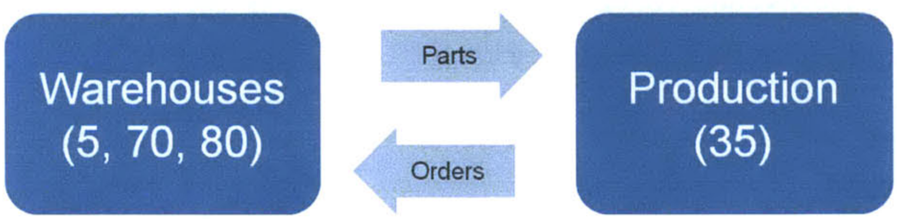

Figure 1-4: Process Flow

However, within this time, many things can happen. This includes the workers being ahead or behind schedule. It also includes the customer changing the schedule (delaying, expediting, or canceling orders). When this happens, the incorrect parts are already on their way and new parts need to be ordered. This means that more parts are moving through the system, which is more work for everyone. Also, these additional parts will take another twenty-four hours to get to the production floor.

The team was initially tasked with reducing the twenty-four hour turnaround time to eight hours, but they will also analyze the root of the problem and suggest other changes that would be beneficial.

The scope of this project will be working with the manufacturing and warehouse management teams at Varian. Changing the design of the machine or interactions with customers to reduce the number of SKUs is out of the scope of this project.

1.4 Task Division

Research performed for this project was divided into three areas. Prachyathit Kanburapa studied the prioritization and control of picking [9]. Obehi Ukpebor studied warehouse layout [10]. Ryan Surveski studied process flow planning [11].

Together, improvements in these three areas will reduce the lead-time for parts going to the production floor. Picking is a complicated and large part of why this process takes so long, and research in this area will have a significant effect on overall lead-time. The warehouse layout is especially critical because picking as well as the majority of the work done to move parts is performed in the warehouse. Finally, the process flow planning will ensure that the individual processes in both the warehouse and production floor are working efficiently as a system.

Prachyathit Kanburapa's research deals with prioritization and control of picking, which includes creating plans to prevent the parts from staying overnight and improving picking speed and capacity.

Obehi Ukpebor's research on the building layout investigated the type and location of consolidation areas and whether or not a kit room is needed. Other improvements are painting the floors, keeping the aisles clear, and improving inventory accuracy.

Ryan Surveski's research on process flow included finding the optimal worker shift distribution, investigating the trucking frequencies, and determining the optimal scanning locations.

2. Literature Review

The approaches used in this research were informed by work in six specific areas: warehouse design, picking, warehousing technologies, mass customization production, tracking parts, and worker shifts.

2.1 Warehouse Layout Design

Warehouses are very important factors that contribute to the success of businesses involved with manufacturing and/or distribution. Operations out of warehouses are important and can determine the success or failure of businesses. It is therefore necessary to carefully plan the design and implementation of a warehouse.
Literature reviews of previous work indicate that there is currently no comprehensive systematic method of going about designing warehouses. The following however is a proposed framework based on review of literature work dating back to 1973, as well as recent studies on warehouse design companies. It represents the general steps followed in designing warehouses. These are shown below [12].

1. Define System Requirements
2. Define and obtain data
3. Analyze data
4. Establish unit loads to be used
5. Determine operating procedures and methods
6. Consider possible equipment types and characteristics
7. Calculate equipment capacities and quantities.
8. Define services and ancillary operations
9. Prepare possible layouts
10. Evaluate and assess

2.1.1 Layout Design

When looking at this problem from an order picking perspective, the layout design can be divided into two focus areas: the layout of the warehouse containing the order picking system and the layout within the order-picking system [13]. Order picking in this section is primarily a manual-pick ordering system as opposed to the use of an automated storage and/or retrieval system, except where stated.

Layout of warehouse containing order picking system

The layout of warehouse containing order picking system involves looking at the warehouse from a broader systems perspective. It takes into the consideration the locations of the different workstations or departments, such as receiving, picking, storage and shipping, as well as the interaction between them. The primary interaction of interest is the movement of material from one to another, with the objective of minimizing the handling cost. The handling cost has also been identified to be directly and linearly related to the travel distance between these workstations [13].

It is common practice to measure layout efficiency in terms of materials handling costs. These can be approximated using the following cost functions. The first objective function is to maximize the closeness of various areas that interact, and the second objective function is to minimize the distance between them [14].
Department adjacencies cost function:

$$max \sum_i \sum_j r_{ij} x_{ij} \qquad (1)$$

Travel distance cost function:

$$min \sum_i \sum_j f_{ij} c_{ij} d_{ij} \qquad (2)$$

Where

r_{ij} – a numerical value of a closeness rating between areas i to j

x_{ij} – is 1 if i and j are adjacent, 0 if not

f_{ij} – the flow from i to j

c_{ij} – cost to move one unit of load from one department to another

d_{ij} – distance from i to j

These cost functions can also be modified for application to multi-floor warehouses where vertical travel distances become significant as well as internal picking systems.

Layout of warehouse within order picking system

Looking within the order picking system involves taking into consideration the configuration of the aisles. The considerations include the number of storage blocks as well as the number, length, and width of aisles within the picking area. Figure 2.1 below shows these areas. The most common objective function when designing a layout with respect to these factors is travel distance [13].

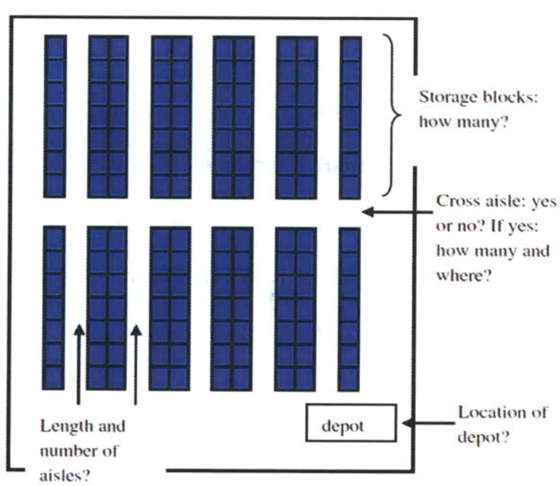

Figure 2-1: Typical layout decisions in order picking system design (top view of storage area) [13]

In random storage warehouses with no real dedicated storage locations for parts, designing a layout becomes even more complicated. Non-linear objective functions have also been proposed to tackle this. These take into consideration the average travel time in terms of the number of picks per route and pick-aisles for determining the aisle configuration [15]. Such models work for any routing policy adopted, provided the objective function expression below is available to calculate the average travel distances.

$$\min T_m^X(n, y, d) \qquad (3)$$

This function gives the average travel distance of the any routing policy adopted X, in a picking area with n aisles of length y and depot located at d, given that m products have to be picked per route, with all variable subject to certain constraints [16].

Methods have also been developed to analyze both random and volume-based storage assignments. For these, simulations have been used in showing the effect on aisle lengths and number of aisles on the total travel time [17].

Types of picking areas in warehouses

It is also important to consider the type of areas involved in the warehouse, with respect to storage of items. In some warehouses, there are dedicated storage areas identified as fast-pick areas. Other common types of areas are unit-load area, carton-pick-from-pallet area, piece-pick-from-carton area [18]. These areas are described below. It is important to note that any of these areas could be in fast-pick areas; however the latter two are most often used.

Fast-pick Area

Fast-pick areas are storage locations in a warehouse that can be quickly and conveniently accessed, relative to other areas. They are strategically located in the warehouses to improve operations. Parts with high flows and demand are often stored in small quantities in these areas.

Unit Load Area

Simplest type of warehouse is a unit-load; common unit of material handled at a time, where unit load is typically pallet. Space and labor scales as pallets are standardized and handled one at a time. WH expenses usually by the square-foot of space, so need to maximize usage, so want many pallet-positions per unit area. Take advantage of vertical space and deep lanes.

Carton-pick-from-pallet Area

For such areas, the handling unit is a usually a carton or case that weighs between 5 and 50 pounds and can be handled by one person, is conveyable, and can be stored on a pallet [18]. When handled in volume, they are usually stored on pallets and restocking is a unit load process

Piece-pick-from-carton Area

In this area, products are handled at the smallest unit-of-measure. Operations in this area involve picking individual parts from cartons, so it is majorly labor-intensive. Also, neither picking nor restocking in unit load [18].
In deciding a layout structure, it is therefore necessary to consider and separate these different storage areas, as well as consider separating the different picking activities in such areas.

Picking areas, storage assignment policies, routing policies and many other factors that need to be considered makes the order picking problem a complex one. These are all crucial factors that need to be addressed in coming up with layout designs and company operations that improve efficiencies. Section 2.2 in this chapter discusses more about the picking literature and approaches towards solving and improving picking problems.

2.1.2 Preparing layouts

In drawing up layouts, computer-aided design (CAD) software is most often used [12]. There are a large number of software packages available for this purpose, but the most common one used is AutoCAD [19].

Drafting warehouse layouts is an important step in this process. A common approach in formulating a draft layout involves the use of plant layout tools such as route sheets, operations schedules, and movable templates drawn to scale to represent freight and equipment [20].

The warehouse layout problem is a complex as there are quite a number of objectives that may need to be satisfied, such as minimizing unused space, increasing part-accessibility, maximizing flow efficiency, as well as flexibility for potential expansion. Some methods of designing and presenting layouts involve the use of block layouts, layout boards and standard templates, conventional or computer-produced drawings, and model methods such as 3D-models [21]. Figure 2.2 below shows a typical block layout with the warehouse functions and flows.

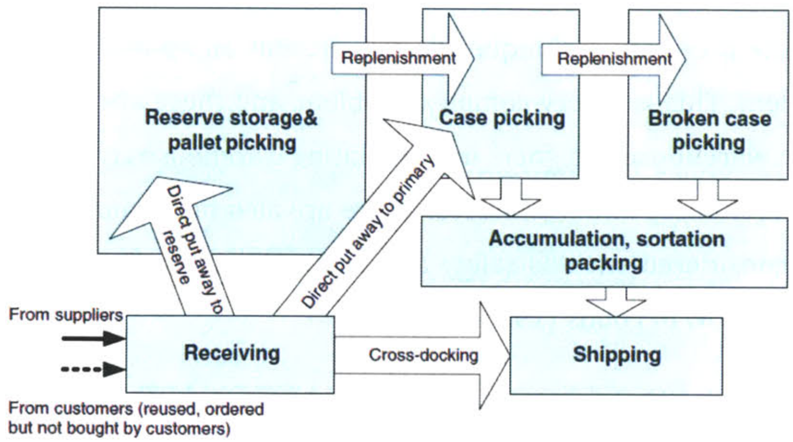

Figure 2-2: Typical warehouse functions and flow [22]

Having designed and prepared the layout, the next step involves [23]:

- **Space requirement planning:** This primarily involves determining the amount of space required for different departments or areas in the warehouse.

- **Material flow planning:** This involves the determination of overall flow patterns in the warehouse, such as a U-shaped flow between aisles, or a flow-through pattern.

- **Adjacency planning:** This deals with the location of different areas. Involves the use of warehouse activity relationship charts as a deciding factor. These charts information are also used as input to computer-aided layout tools in locating areas.

- **Process location:** This involves splitting areas in low-rise and high-rise usage, depending on operations in specific area.

- **Expansion or contraction planning**: This involves taking into consideration potential changes to the warehouse, especially with respect to expansions.

Despite the abundance of literature work on the design of warehouses and layout structures, the proposed techniques do not present an optimal way of solving the layout problem. This is a very complex problem, and these are general procedures to aid expert warehouse designers in formulating warehouse layouts. Layouts vary a lot across warehouses and businesses. There are also many qualitative factors that need to be considered such as safety and aesthetics, as well as other quantitative factors such as flow of goods [19].

Dealing with Existing Layout Designs

The methodologies presented above apply to both new layout designs as well as redesigns; however the purpose of this section is to highlight some of the important factors that also need to be considered for redesigns. This is important because a large number of layout decision cases take into consideration the fact that a design has already been implanted, but needs improvements, and obstacles in the current design may not be re-locatable or incur a non-negligible moving cost [24].

It is therefore important to evaluate and size the moving cost of various areas in an existing design. A way of sizing the moving cost of a new design involves generating the design space of the existing design at multiple levels, marking up areas based on their relative weights of moving cost at each level, taking out areas with minimal moving cost, and then creating a variety of designs [24].

It is also important to take into consideration the timing of moves and its impact on current operations and the overall costs of redesigning. This is because moving some areas might lead to temporarily taking down some areas depending on the availability and clearance area for moving things around. Some operations may also exist which cannot be stopped for a long time if need be. It is therefore necessary to plan any changes or redesign in such a way that implementation is feasible and major costs have been identified.

2.1.3 Other structural factors considered

Racking vs. Stacking

Racking is the most common method adopted in most warehouses; however, the setup varies from warehouse to warehouse depending on a company's operations. In some cases, warehouses have no definite structure adopted for the location of racks as well as parts. There are different sizes of racks, depending on the size of parts being stored. The major dimensions include overall height, row heights, and length of racks.

When dealing with pallets or unit loads, it is important to consider the storage system. Some pallets can be stacked high, others cannot, because they are fragile or heavy, so may end up with wasted unused space. To maximize pallet position per unit of floor space, it is useful to install pallet racks for independent storage of racks [18]. The amount of pallet racks to have and what to be stored strongly depends on the value. This value depends on the size and movement patterns. There is also an economic argument to making this decision.

The following are benefits of putting SKUs in racks versus leaving them on the floor. They may:

- reduce labor as product is easier to store and retrieve; savings realized as increased throughput or reduced labor requirement
- create additional pallet position, more storage space per unit area. May lose space if SKU is too high and ceiling becomes a barrier. May be able to stack 3, one on top the other, but with racks, may only be able to rack 2 before reaching ceiling height.
- help protect material from damage by forklifts for example. Hard to quantify savings, except comparison to past experience
- provide safer work environment, avoiding unstable pallet stacks. Hard to quantify saving here too

So, on a SKU-by-SKU basis, there is a need to estimate the savings for each of the categories above. These saving can them be compared to the cost of installing pallet racks, and a decision can be made on the design if it the changes or benefits are economically justified. This analysis can also be performed for different rack configurations to determine which is of greatest value.

Lane Depth

The question here is accessibility, not storage. Aisles space provides this accessibility. Need to reduce aisle space to the minimum to provide sufficient access. Need to be at least wide enough for a forklift to insert or extract a pallet. Storing products in lanes, pallet positions can share aisle space to potentially offset cost of the extra space. Depth of lane depends on so many factors, but what's important is effective utilization of space. Double-deep layout (two-pallet positions deep) fits about 41% more pallet positions in the same floor space as single-deep. Whether it is better depends on accessibility. If towards the end of wall (aisle only on one side), all single-deep SKUs are readily accessible on the go, but half of double-deep are not. So there's a diminishing value with deeper lanes, although they produce more pallet storage location.

2.2 Picking

Order Picking System (OPS) is the process of retrieving items from the storage locations in response to the internal or external customer requests. An OPS is typically considered the most labor intensive and costly activity for almost every warehouse. The operational cost of order picking is estimated to account for 55% of the total warehouse operating cost [22].

In practice, the design and optimization of OPS is carried out under a certain objectives based on companies' tactics or strategies. Objectives may include minimizing the retrieval time of an order or a batch of orders, maximizing the space, equipment and labor utilization, and minimizing the total cost. Most of the researches conducted in the past identified the retrieval time as the most prominent areas to improve as it is directly related to the service level. Moreover, short retrieval time implies high flexibility in handling the late order change [13].

2.2.1 Classification of Order Picking System (OPS)

Dallari et al. proposed the comprehensive classification of OPS as shown in Figure 2-3. A four-level decision tree questions consists of: who picks good (humans or machines), who moves in the picking area (pickers or goods), is conveyor used to connect picking zones, and what is the picking policy (pick by order/pick by item)? Based on these questions, OPS can be classified into five categories:

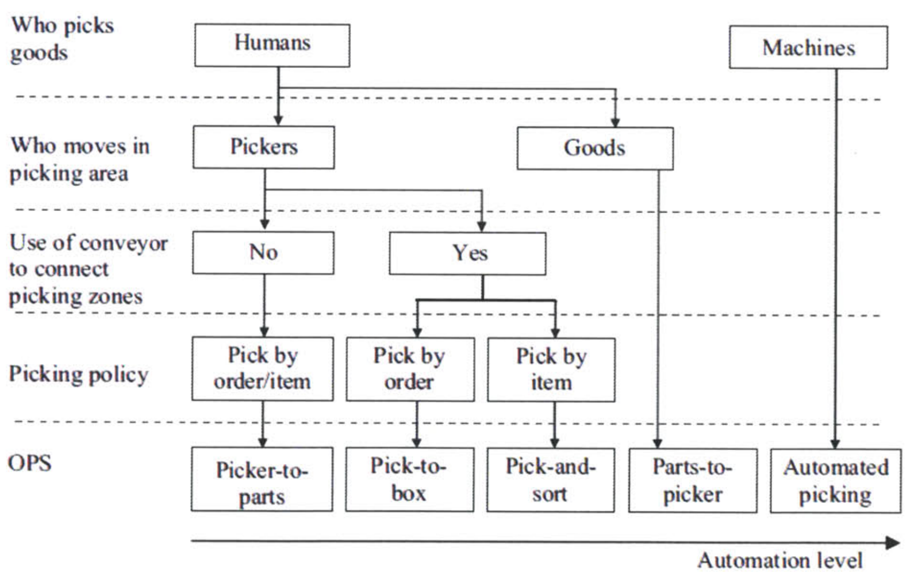

Figure 2-3: Classification of OPS [25]

1) Picker-to-parts

The majority of the picking methods employed worldwide is the low level, picker-to-parts, human picker method. This method covers more than 80% of all order-picking system in Western Europe [13]. In the low level picker-to-parts method, pickers travel along the aisle and retrieve the items from the storage location. On the other hand, high level picker-to-parts method involves a crane that automatically moves pickers to the appropriate location.

2) Pick-to-box

This method falls into a category where there is a conveyor connecting picking zones. Pickers place items in the boxes corresponding to a certain customer order and the boxes are moved through the conveyor to the next picking zones. Pick-to-box method can be considered as "sort-while-pick" method [13]. The advantage behind this method is the reduction in the travel distance and time.

3) Pick-and-sort

This method is similar to pick-to-box method as the conveyor is used to connect picking zones. The difference is that the multiple orders are released at once in a batch. The sorting is done after the picking either manually or using a computerized divert mechanics such as tilt-tray.

4) Parts-to-picker

In this method, an automatic storage such as carousels and vertical lift modules (VLM) brings the items to the pickers. Not only does this method reduce the picker's distance traveled but also safe a huge amount of storage space.

5) Automated picking

This OPS is fully automated. Its use is limited to a very small and delicate item. This method is out of scope for this thesis and will be ignored from here on.

2.2.2 OPS time breakdown

The time constituting the total order picking time can be categorized into three types [23]:

1. Travel time – within aisle and across aisle "travel" time
2. Process time – searching for pick locations, extracting items, scanning documenting picking activities
3. Administrative time – obtaining a pick list, getting and depositing the picking device or vehicles

Travel time has always been considered as a dominant part in order picking. According to Tompkins et al., 50% of the order picking activity is spent on traveling [22]. The typical distribution of the order picking time is shown in figure 2.4. Travel time consumes labor hour without adding any value hence it is the first area to be improved.

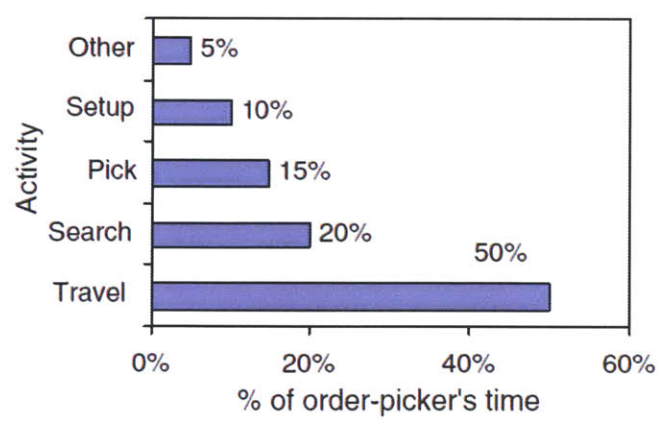

Figure 2-4: The typical distribution of order-picker's time by activity [22]

2.2.3 Typical area of improvement

Routing policy

The routing problem deals with sequencing the pick orders to achieve minimal travel distance. It is a special case of the Traveling Salesman Problem (TSP). In the classical TSP, a salesman has to visit all the cities exactly once, the distance between cities are given and the task is to find a route with minimum travel distance. Routing methods in warehouse settings is a special case when there can be cities where the salesman can choose not to visit or visit multiple times. This problem is called a Steiner Travelling Salesman Problem (STSP). An algorithm to solve this problem was presented by Ratliff and Rosenthal in 1983 [26].

Nevertheless, the optimal solution is rarely found implemented in practice because not every warehouse layout has the optimal solution and the solution does not take into account the case of more than one picker. Heuristic method instead is more commonly used in the warehouses. Roodbergen explored several heuristic routing methods as illustrated in Figure 2.5 [15].

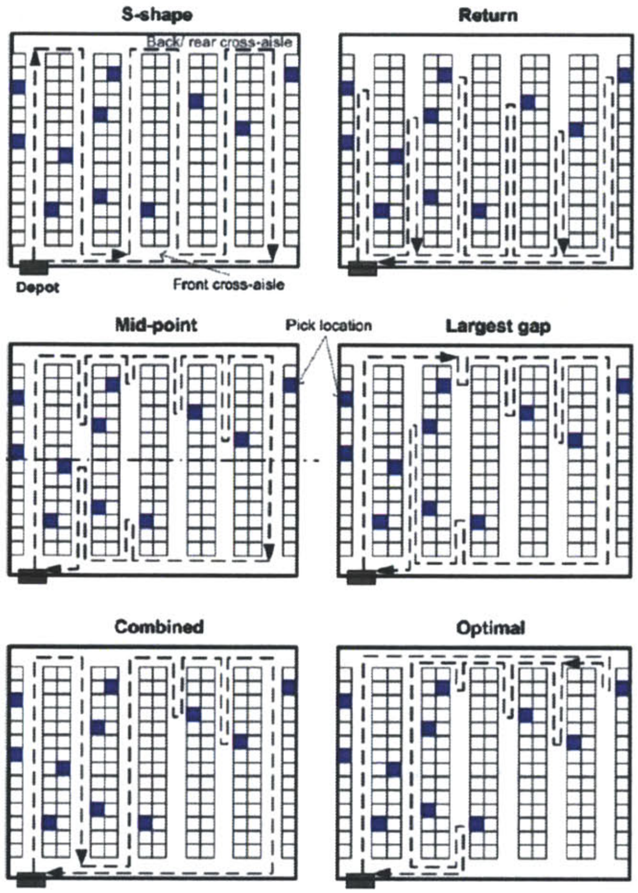

Figure 2-5: Common heuristic routing methods for a single block warehouse [15]

In the S-shape heuristics, aisle with at least one pick order is traversed entirely. Pickers enter the aisle at one end and exit at another end. Picker enters and exits aisle in the same end for the return policy. Mid-point heuristic divides aisle into half and the return policy is applied to each half. The difference of the largest gap heuristic from the mid-point heuristic is that the picker travels as far as the largest gap within the aisle.

It has been shown that when the number of pick per aisle is as low as one pick on average, return policy outperforms S-shape policy. In addition, the largest gap method always performs better than the mid-point method. However, the mid-point method is a lot simpler from the operational standpoint [27]. A numerical simulation was also performed on these 6 types of heuristics. The conclusion is the heuristic methods that perform best are on average 5% longer travel distance than the optimal solution [28].

Storage assignment policy

Items have to be put away to the storage location before they can be picked. Depending on the storage policy employed, there is a trade-off among various factors such as travel time, space utilization, and familiarity of pickers. According to De Koster et. al., five regularly used storage policies are: random storage, closest open location storage, dedicated storage, full turnover storage, and class-based storage [13].

In the random storage policy, items are assigned to the random empty storage location having an equal probability. High space utilization is achieved at the expense of long travel distance. For the closest open location storage policy, workers identify the closest empty storage location to assign the item. The racks will be full near the depot and gradually decreases as further away from the depot. Dedicated storage policy assigns a particular item to a dedicated storage location. Therefore, some bins can be reserved even though they are empty which leads to low space utilization. In the full turnover policy, items are stored based primarily on their picking rates. The most frequently used metric also take into consideration the size of the items and is called cube-per-order index (COI). COI is the ratio between the size of the item and the average number of orders per period [29,30]. Drawback of this policy is when the demand fluctuates a lot, the reassignment have to be made frequently.

The difference between class-based and full turnover policy is that for class based, items are grouped into classes of metrics such as COI. Conventionally, fastest moving group of parts are called A-class item and the second fastest moving group of parts are called B-class item and so on. Petersen et. al. simulated the class-based with different partitioning strategies and the full turnover policy. The results shows that full turnover policy achieve less distance travel with the expense of implementation complexity. It is suggested that the number of classes should be between 2-4 classes [31]. In case where there is a significantly high correlation of items to be picked together, family grouping method can be incorporated in the policy.

Zoning

Warehouse can be split into zones with an assigned picker. This can reduce the picker's travel distance significantly as well as congestion problem. The downside of this method is the fact that the items from different zones have to be later consolidated. In general, different zones are separated based on size, weight and require storage conditions [13].

Melemma and Smith also studied the aisle configuration, stocking policy, batching and zoning and suggested that the combination of batching and zoning can greatly improve warehouse productivity [32]. Brynzer and Johansson brought up an interesting point about workload balancing when implementing the batching and progressive zoning methods together [33].

Order Batching

Order batching is a method of grouping multiple orders to a single picking tour. Choe and Sharp categorized the grouping criteria into two types; by proximity and time windows [34]. Proximity order batching combines orders based on the storage location proximity. Pick orders that contain parts that are stored in close proximity with each other are grouped together. Time window order batching, on the other hand, groups orders within a certain time frame together. The sorting can be done during the picking (sort-while-pick) or later at the consolidation stage.

2.3 Other Warehousing Technologies

In an effort to solve the layout and order picking problems, technologies have been developed to facilitate the automation of storage and retrieval systems. Below are two robust systems that have been developed are operational in a number of warehouses.

VLMs

With the use of VLMs, the distance factor becomes less significant, as the machine does majority of the picking. The pickers or VLM operators only have to travel the width of the VLM tray, and move picked parts to next VLM station, or to the consolidation area. However, not all companies are large enough to get the benefits of a VLM. In situations like this, rack or shelve locations

KIVA Systems

With KIVA, robots (shelves) do the travelling to pickers, but warehouse has to "very" large to get the benefits. This has a large capital cost involved with it, and travel distance of robots is also complex problem that requires sophisticated algorithms and programming methods.

2.4 Mass Customization Production

In a mass customization production environment, the products being produced have many options and the manufacturer must listen to what the customer wants. Pleasing the customer is important in these places, but so is cost and speed. To achieve this, the production must be flexible, and ideally have short lead times on delivering parts [35].

2.5 Tracking of parts

Several methods of tracking parts are used in industry. If production or the number of SKUs is low, parts may be able to be tracked by manually entering data. However, for many companies this is not possible. Two of the main options available are barcodes and radio frequency identification (RFID).

As the increase in number of SKUs occurs and a company wants to implement barcode scanning or RFID, there are several things to be considered. One is the number of warehouses. If the warehouses can be consolidated to one, this will make implementing the new methods easier. Also, in addition to the barcodes or RFID on all the parts, hardware and software for scanning and tracking is needed [36].

Barcodes and RFID have different advantages. Barcodes have the advantage of being very cheap. RFID has the advantage of efficiency, as the worker does not have to line up the scanner with the barcode.

2.6 Worker Shifts

Many companies use a shift system so that the company can manufacture more by increasing the number of workers and not needing to increase capacity of the plant. However, many workers do not want to work overnight and it can also be bad for their health.

2.6.1 Permanent and Rotating Shifts

In shift work, some companies choose to use permanent shifts. This means that any given worker will work the same schedule every day they work. For example, one worker may work 7:00am to 3:00pm every weekday. Another worker may work 7:00am to 7:00pm every Friday, Saturday, and Sunday. The alternative is rotating shifts. With rotating shifts, each worker may work a mixture of shifts. This could mean that a given worker works in the morning on Monday, then evening on Tuesday, and then overnight on Thursday, Friday, and Saturday. This may even change from week to week.

There are pros and cons to each of these approaches. Permanent shifts have the advantage of being easy for the company to schedule. They also provide consistent schedules for the workers week after week. They also allow some of the workers to never have to work the shifts they do not want to (usually the night shift). Rotating shifts on the other hand allow flexibility in workers schedule, as they may be able to choose when they want to work different hours [37]. It also can make it easier for the company to find night shift workers, because they do not have to do it all the time.

Further, there are other factors that may vary based on person and company. For the company, the amount of workers on each shift matters. If there are many people working all the time, then rotating shifts may be easier to implement than if there are only a few workers. Also, the different sleep schedules during night shift work make it hard on many people, but some may prefer the permanent night shift to alternating, or visa-versa [38].

3. Preliminary Analysis of Operations

This section's purpose is to outline the current way that Varian moves parts. This includes everything from receiving parts from outside suppliers to when the part is in the hand of a production worker.

3.1 Process Flow

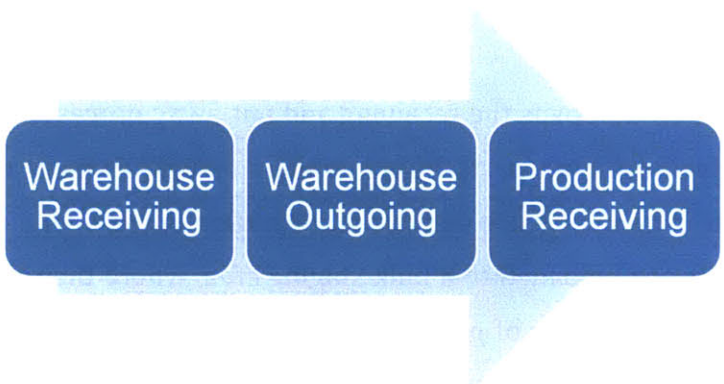

Figure 3-1: Process Flow

As seen in Figure 3-1, the three main stages of part movement are receiving at the warehouse (building 80), picking and outbound from this warehouse, and receiving at production (building 35).

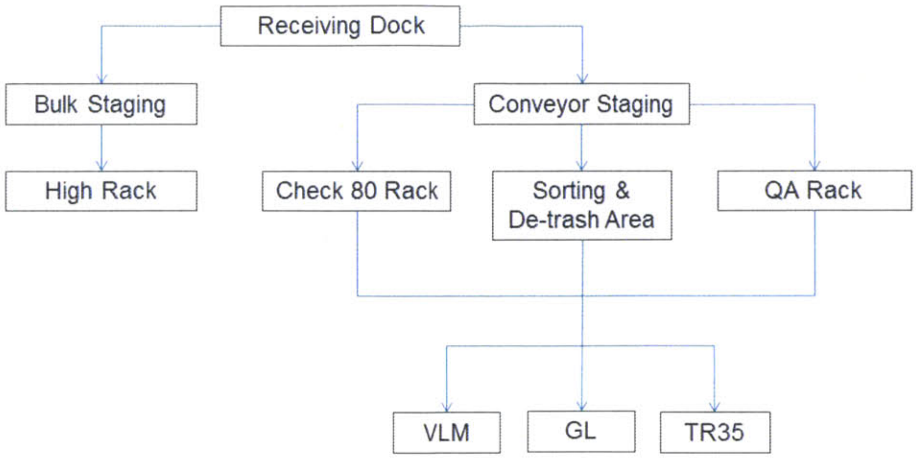

Figure 3-2: Receiving in Building 80

The process in Figure 3-2 depicts the receiving and put-away process for parts coming into building 80. This includes both parts from suppliers as well as parts coming from other buildings at Varian. When parts are delivered to building 80 receiving dock, they are first unloaded. Bulk parts are unloaded to a bulk staging area, where they are tagged with bar-coded labels to indicate receipts of parts as well as assign a storage location and staged to be put away. These parts are then put-away in the high-rack storage location areas in the warehouse.

The smaller boxes are dropped off on a conveyor staging area. The boxes are opened to ensure that all the parts are there as indicated on the purchase order. Once this is done, a bar-coded label is put onto the box and a storage location for the parts is assigned. These parts could then go to any of three places: Check 80 Racks, Sorting & De-trash area, or QA Rack. Majority of the parts are sent to the Sorting & De-trash area, where the count of parts received is checked and the parts are set on shelves, ready to be put away to the VLM (Vertical Lift Module) or GL (Gloucester) storage locations in the warehouse, or to TR35 (outgoing truck staging area). Cross-dock parts go to TR35, as they are received in the warehouse, but are actually needed in a different building. Someone doing put away will then scan the parts off this put-away shelves and put away in their corresponding storage locations.

Of the parts that do not go to the Sorting & De-trash area, some go to the QA Racks and others to Check 80. The parts that go to QA Racks need to go through a quality control station before being put-away to storage locations. Parts that come in without dimensional or weight information must be diverted to the check 80 station for measurement.

Some parts received in the warehouse are shortage parts required to complete an order or on-going assembly. These are handled slightly differently. These parts get put in a bin for shortages and are accelerated through the process. These parts are put in brightly colored marked shortage bins and workers will know to handle these parts first.

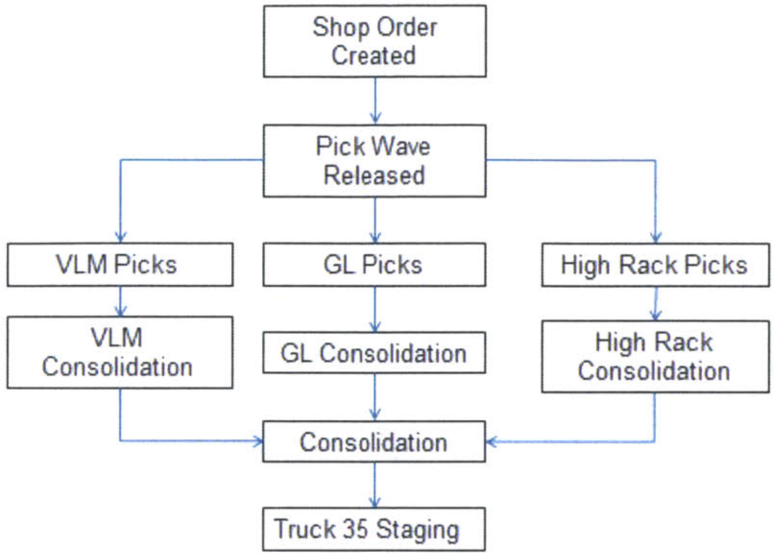

Figure 3-3: Picking and outbound in building 80

Figure 3-3 above presents a summary of the picking process performed in the warehouse. When production orders parts, they create shop orders. These orders are entered into the SAP system which the warehouse also has access to. At the warehouse, a worker accesses these shop orders and releases them periodically as pick waves to the warehouse pickers, making them available to the pickers to access and see the exact parts they have to pick for released shop orders and their storage locations.

After the waves have been released, three main types of picks are made. The type of pick made corresponds to the storage location a part is picked from. The three main types of picks are VLM, GL, and High Rack picks. Parts in High Racks are picked with the aid of cherry pickers and forklifts, while parts in GL are manually handpicked from racks. The VLMs mechanically eject trays for parts to be manually picked from.

A shop order often contains picks from all three storage locations. They also require multiple parts to be picked from each storage location. All the parts needed for a shop order are grouped together under a unique consolidation group number regardless of where they are picked from, and as such need to be consolidated after being picked from the different locations. Therefore, a consolidation process is required for parts from each pick type.

VLM consolidation involves the grouping of parts picked from the VLM that belong to the same consolidation group or shop order. Similarly GL consolidation and High Rack consolidation involves the grouping of parts from the GL and High Rack areas respectively that belong to the same consolidation group.

Once consolidation of parts from the any of the pick areas is done, this group of parts is moved to a different consolidation area where it waits for group of parts from the other pick areas that they will be delivered with. For example, once VLM consolidation is done, the group of parts is moved to a consolidation area where it waits for parts from the GL and High Rack areas.

Grouping these parts is almost essential because hundreds of parts are delivered each day. Once all the parts in a group are present, they are packaged together if possible and recorded in the computer as one handling unit.

This group of parts is then moved to the Truck 35 Staging area, and prepared to be sent on the next truck to building 35.

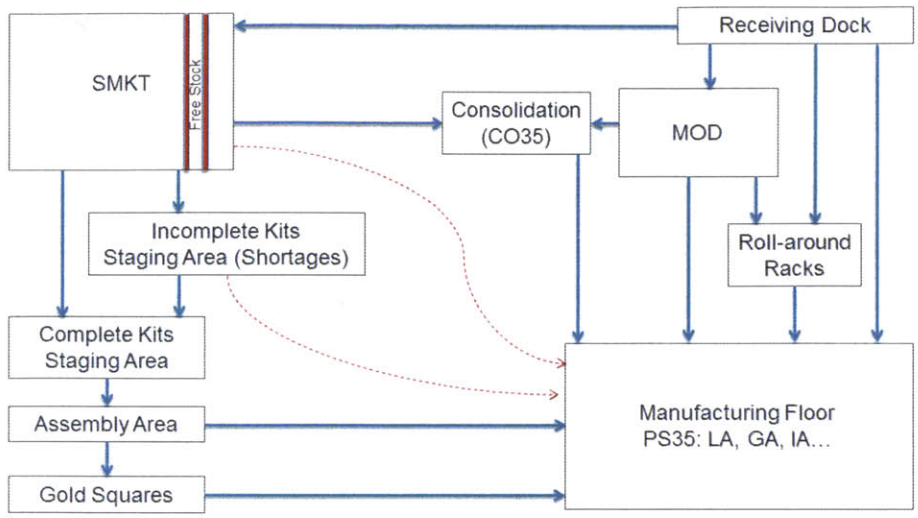

Figure 3-4: Receiving at building 35

Finally, the receiving process at building 35 can be seen in Figure 3-4. The process starts at the top-right corner of the chart, the receiving dock. Here, trucks delivering parts from building 80 or other suppliers arrive at the dock. The truck is unloaded, pallets are unpacked and everything is de-trashed further.

Parts received at the dock can go to any of four areas: SMKT, MOD, Roll-around Racks or the Manufacturing Floor. SMKT and MOD are storage locations. SMKT is for storing smaller parts required for mainly sub-assemblies, while MOD is for larger components required to build a module. When production orders parts, some of the parts also come from the SMKT and MOD storage areas, besides the storage areas in building 80 (warehouse). SMKT parts and MOD parts under the same consolidation group or shop order get consolidated together in CO35 consolidation area, before being delivered to the Manufacturing Floor. Parts from building 80 get consolidated with MOD parts in the Roll-around racks, before being delivered to the Manufacturing Floor.

Parts needed for sub-assemblies get picked as kits from the SMKT area. A kit is a group of parts required for a sub-assembly. When all the parts required for a kit are picked from SMKT they get staged in a Complete Kits Staging area, from which they are then delivered to the Assembly area where they are assembled. Incomplete kits which have shortages are staged in an Incomplete Kits Staging Area, until shortages arrive to complete the kits after which they are delivered to the assembly area. After assembly is complete, these sub-assemblies are either delivered straight to the Manufacturing Floor or to the Gold Squares which Manufacturing pull sub-assemblies from as needed. The Gold Square are racks used to store common sub-assemblies which are repeatedly demanded by production.

All parts are ultimately delivered to the manufacturing floor, so all arrows lead there as depicted in the figure.

3.1.1 Vertical Lift Module (VLM)

In Figure 3-5, a set of three vertical lift modules in building 80 can be seen.

Figure 3-5: Vertical lift module

Vertical lift modules are storage devices that allow many parts to be stored in a small area. Inside each VLM are many shelves; the exact number varies depending on the height and spacing. Each shelf can be configured with the desired bin sizes. The shelves can be moved internally in the module, and one shelf at a time can be slid out for picking. The computer knows which part will be picked next and automatically slides out the correct shelf. Finally, a light will light up on the machine, indicating a more specific location of the part that is being picked.

The first three pods of VLMs (nine units) started operating in May 2012 and then were integrated with EWM when it launched in August. All five pods (fifteen units) were operational with EWM by January 2013. Overall, the VLMs have a small footprint, but because of their height and design, can hold many parts. It is a great way to densely store parts and take advantage of the height available in the warehouse, but still having the parts accessible.

3.2 Time for Each Step

When production orders parts to building 35, the promised turnaround time was twenty-four hours as mentioned by the Materials Flow manager, when this project began.

To further investigate this turnaround time and the major steps involved with fulfilling these orders, SAP data was analyzed. Parts ordered by production for machine builds were tracked all the way from when they were ordered to when they arrived at the main building. Figure 3-6 below presents the distribution of time it took for parts to arrive. This data is based on over 12,000 parts ordered for 27 machines that were completed between February and May of 2013.

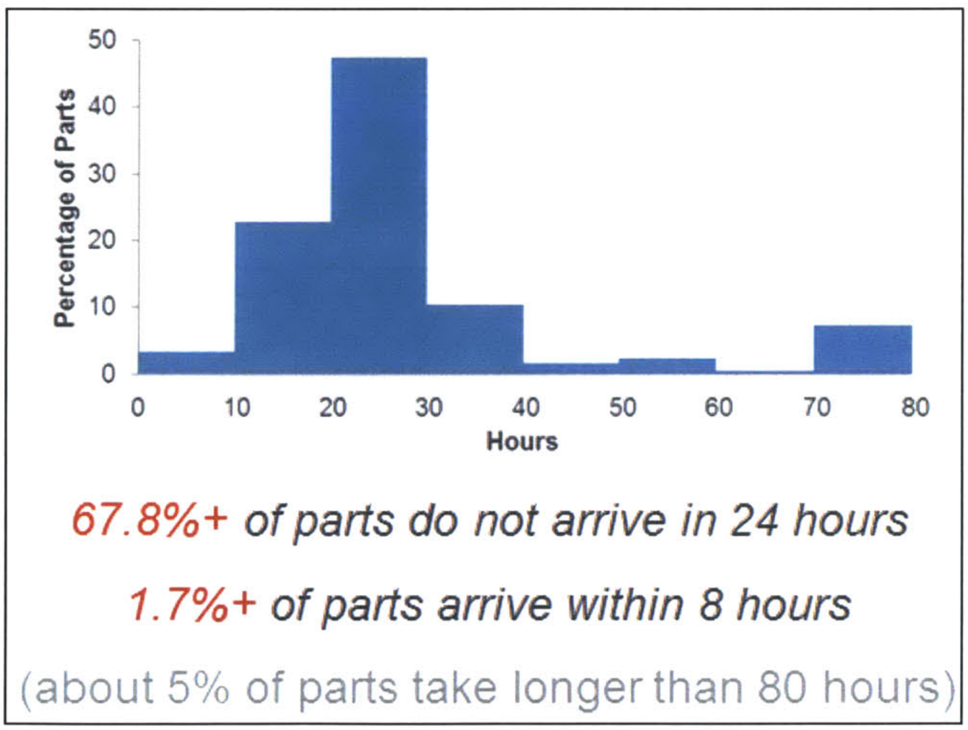

Figure 3-6: Distribution of time parts arrive

The time it takes for parts to arrive can be broken down into six major time steps involved with fulfilling orders, as identified from the SAP data. These include the time an order was placed, when the order is released as a wave to pick the parts, when the part is picked from a storage location, when it is delivered to the consolidation area to wait for other parts it is grouped with, when the consolidation with other parts is compete, and when the part is delivered to the production dock in the main building. Figure 3-7 below shows the average time obtained for each step based on the data used to obtain the time distribution in Figure 3-6.

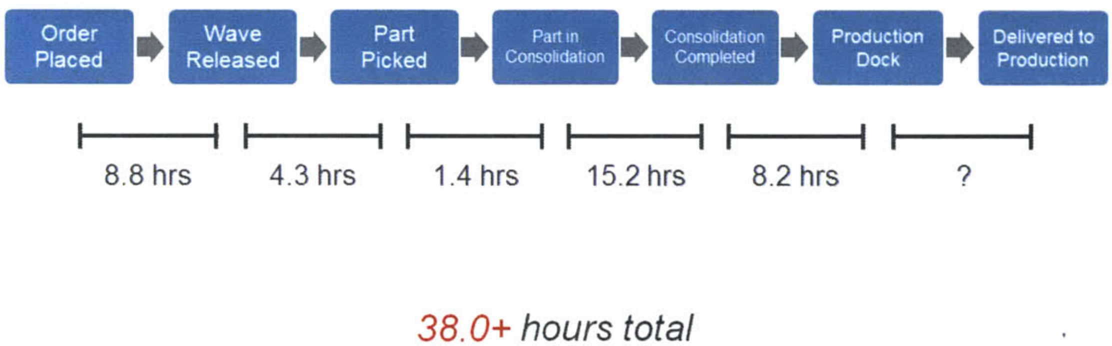

Figure 3-7: Time for each step

It is important to note that the seventh step which is when the part is actually delivered to production from the production dock cannot be obtained from SAP data and is not tracked. For the purpose of this analysis, it is assumed that this time is significantly less than the other time steps identified.

While many people at Varian Semiconductor thought that the 24 hour turnaround time was being met, Figure 3-7 shows that this was not the case.

3.3 Inventory Accuracy

At the start of this project, inventory accuracy was measured both in building 80 and building 35, by the Inventory Control employees. The inventory accuracy is measured based on the percentage of first counts of the amount of parts in a storage bin or location that match the amount the SAP system indicates is on hand in that location. Each day, SAP randomly generates 30 storage bins or locations for these counts to be made. Two employees conduct these counts. For a count to be considered off the parts stored in that bin or location must have at least a $100 value. The Manufacturing Manager mentioned that building 80 saw very high inventory accuracy, around 98%. However, building 35 saw much lower accuracy, around 57%.

3.4 Extended Warehouse Management (EWM)

Varian, like most other large companies uses an extensive software package to manage and track parts. Varian uses SAP and for parts in the warehouses, they previously used the Inventory Management system. The Inventory Management system allowed them to see what parts they had, but not where these parts were located.

On August 19th 2012, Varian started using Extended Warehouse Management instead of Inventory Management. With the new system, the barcodes on each part are scanned at designated locations in the process. This takes longer, but allows Varian to track the movement of parts. When parts go missing somewhere in the process, employees are able to identify where they are likely to be.

The Program Manager mentioned that during the implementation of EWM, most employees received little or no training. This caused problems at the start. He also indicated that even now, most employees know how to navigate EWM for their job, but do not know much more than that.

3.4.1 Scanning Process

EWM is essential for the scanning and tracking of parts, but there are several other critical aspects to this process. These include the scanning guns, the barcodes, and how the workers choose to operate.

Two main types of scanning hardware are used. One is a standalone gun which has EWM installed and can be navigated using the built in screen. The other option is a barcode scanner that is hooked up to a computer. The standalone gun is more portable, but often harder to use.

The barcodes are the next essential part. At Varian, barcodes are applied to parts for identification as they are received in building 80. They are also put on locations such as storage bins, consolidation areas, trucking areas, and receiving areas. As such, when a part is picked or moved from one location to another a scanning transaction can be made with the aid of the barcodes to reflect the movement on EWM, so parts can be tracked. When scanning barcodes, workers have two options. They can scan the barcode on a part and press a button on their computers/gun to reflect the part movement or transaction to the next location for that part, or they can scan a barcode on their picking cart that is associated with that next location to complete the movement. The pickers and receivers who perform these scan operations identified the second option as much faster. Some workers have carts with barcodes representing all the locations parts go to; as such the scanning operation is faster and easier to do.

As mentioned by the Program Manager, the EWM system was implemented to perform scanning operations to better track parts as they are scanned and moved from one location to another. However, observations of current operations and SAP data have shown that workers often adjust how they perform the expected operations of EWM to make things easier. This results in scans being performed earlier than they should be and thus, there is less resolution on the tracking. For example, a part that is sitting in the consolidation area is supposed to be scanned when the consolidation with other parts is complete, and then scanned again when the consolidated group of parts is put onto the truck. The workers however perform these steps all at the same time. This allows them to move parts faster, but as a result, the parts cannot be tracked closely as to whether they have been put on the truck or not.

3.5 Worker Shift Distribution

At Varian there are four shifts, and depending on the group, employees may work during all of these shifts, or just a few.

The start and end time of each shift does vary between different sections of the company. It is also important to note that some of the shifts overlap; the standard overlap is a half hour at Varian. However, fourth shift does have a large overlap with the other shifts, because these workers work on Friday. For this project, the three areas that matter most are building 80 employees, building 35 dock employees, and building 35 production employees. As seen in Table 3-1, the shifts for building 80 and building 35 production are the same, while building 35 dock is different. The table on the left shows the times at which workers in the production and warehouse areas begin and end work. The table on the right shows what time workers for each shift in the receiving area of building 35 start and end work each day. These tables do not show how many people work each shift; this data will be shown later.

Table 3-1: Shift times by group

Shifts in 80 and Production			
Shift	Start	End	Days
1	7:00am	3:30pm	M,T,W,Th,F
2	3:00pm	11:30pm	M,T,W,Th,F
3	11:00pm	7:30am	M,T,W,Th,F
4	7:00am	7:00pm	F,S,Su

Shifts in 35 dock			
Shift	Start	End	Days
1	8:00am	4:30pm	M,T,W,Th,F
2	1:00pm	9:30pm	M,T,W,Th,F
3			
4	7:00am	7:00pm	F,S,Su

Within each of these three areas, there are also differences in which shifts workers are working. The majority of workers in these areas work shift one. The exact breakdown of when people are working can be seen in Table 3-2. The percentage of workers working in a given area at different times during the day can be seen in Figure 3-8. A weekday is represented here, because that is when most people are working and it is also most relevant to the lead time of parts, since they typically are delivered during the week.

Table 3-2: Number of workers per shift by group

Production		
1	48	48%
2	26	26%
3	6	6%
4	20	20%

Building 80		
1	24	80%
2	6	20%
3	0	0%
4	0	0%

Building 35 Dock		
1	9	64%
2	3	21%
3	0	0%
4	2	14%

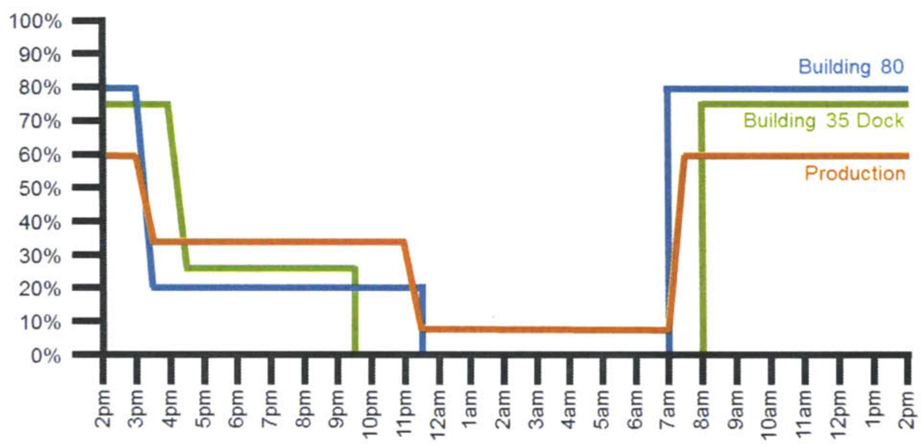

Figure 3-8: Percentage of workers active by shift on weekdays

3.6 Summary of Operations

The value stream map of the process was created and can be seen in Figure 3-9. This value stream map demonstrates the time from the wave being released, to the part being delivered (this does not include the time from ordering to wave release). This shows that the production lead time is 30.7 hours, while the processing time is only 28 minutes. This relatively long lead time shows that the problem is that parts wait for a long time and not because it takes a long time to actually process parts.

In Figure 3-9, production control in the top center is in charge of two things: ordering parts from suppliers, which will go into inventory in the warehouse, and ordering parts from the warehouse. The route that parts take to get from suppliers to the warehouse can be seen in the top left. The information about orders going to the warehouse can be seen going down through the center of the map. Along the bottom of the figure, is the flow of the parts, starting at the warehouse until they get to the production building. Each step in the process has a processing time as well as total time (including any wait time). It can be seen that the processing time for most steps is very low. Finally, in the bottom right corner, it can be seen that parts are sent to production (the customer) which eventually relays to production control the information of whether or not they have the necessary parts. From this, production control knows what additional parts to order, and the cycle continues.

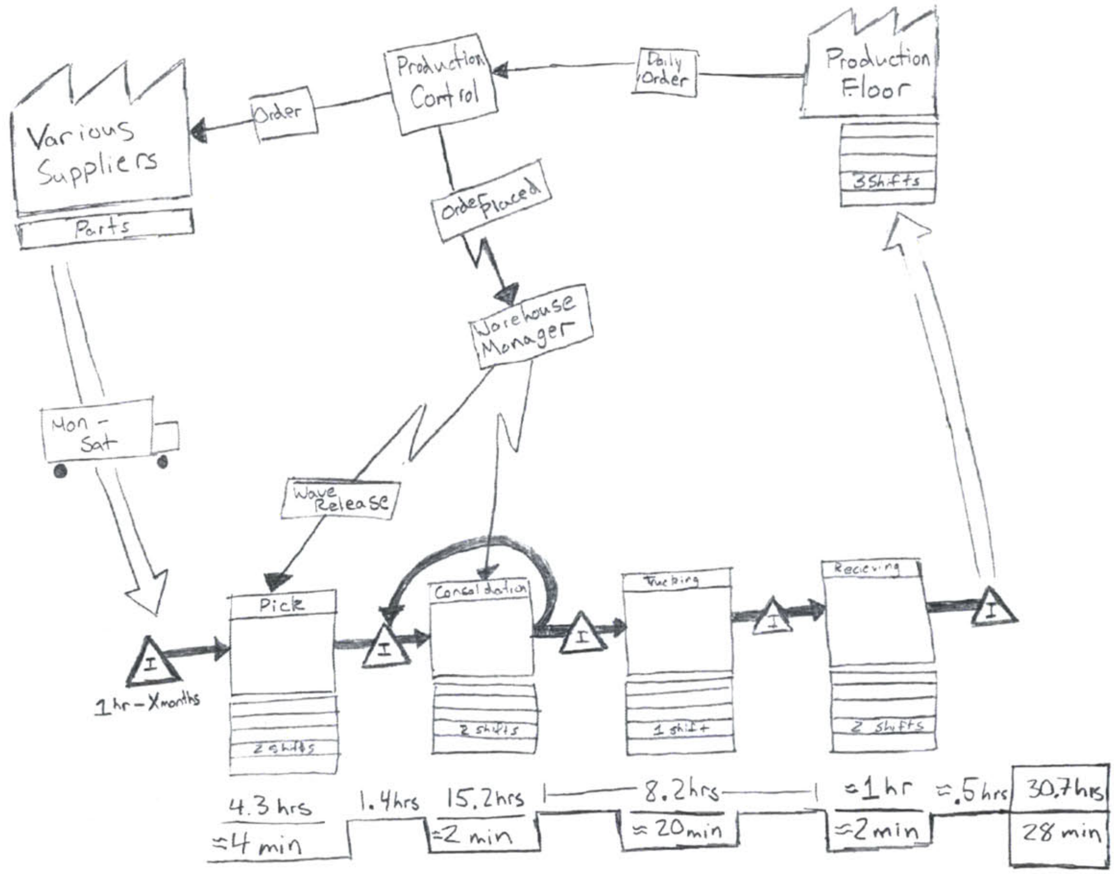

Figure 3-9: Value Stream Map

Much time was spent learning about the operations at Varian. During this, many workers were informally interviewed to gather information. This was done by starting from the "customer" (the production floor) and working backwards. People on the production floor were talked to first, followed by the receiving dock, warehouse shipping, picking, put away, and finally warehouse receiving. They were first asked general questions such as what their role was and why it is necessary. Next, depending on their role, they were asked how they would improve different aspects of Varian's operations. Gathering this information, the team was able to hypothesize why the turnaround time for parts is so long.

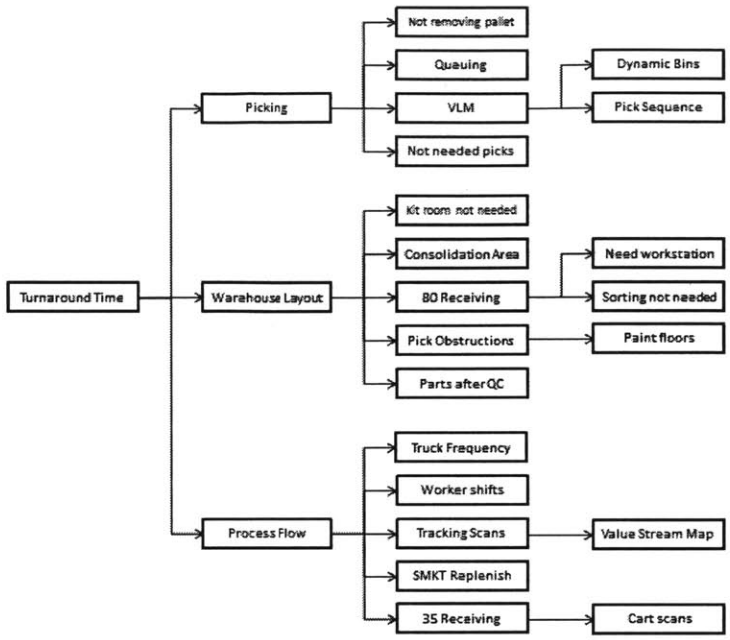

Figure 3-10: Hypothesis Tree

As seen in Figure 3-10, there are three main sections that can contribute to this long lead time.

Overall, the material flow group at Varian is responsible for moving parts between buildings in Gloucester. Parts are primarily moved from warehouses to the production floor.

Despite the use of SAP, vertical lift modules, and other technology, the current time for each part to be moved is much higher than desired

Also, there are some parts of the process for fulfilling orders take much longer than others as seen in Figure 3-7. The longest of these times is when parts are sitting in consolidation, which accounts for about 40% of the total time.

Finally there are many workers on first shift in both production and the warehouses. Currently, production and the warehouse decide on shifts schedules independent of each other. This could mean that they are missing out on potential benefits of coordinating.

4. Warehouse Layout Design Methodology

This section's purpose is to detail the methodology used to address the warehouse layout problem. Each part will discuss how specific areas of the warehouse were approached to produce meaningful and useful results that reduce the turnaround time for ordered materials. A brief summary of the approach is first presented followed by a more detailed method for each focus area of the warehouse.

Much time was spent learning about the operations at Varian, as presented briefly in the Preliminary Analysis section. For the warehouse layout problem however, a series of daily observations of the warehouse operations were carried out for about two weeks. These operations include receiving parts, sorting parts, picking parts, consolidating parts into kits, and moving parts from one point to another in the warehouse. During these observations, workers performing each process were questioned about the processes they carried out.

More data collection was also carried out. The picking and consolidation of parts processes largely involve scanning each part or group of parts as they are picked and consolidated, and as such generate real-time data on SAP. For these, SAP data dating back up to five months were analyzed to obtain time data to figure out what activities took the longest and how they can be modified to save time and speed up material flow.

The layout of the warehouse was modeled as scaled blocks, showing the different workstations and areas. A process flow map was also generated from the layout to show material flow within the warehouse. The layout was then presented in two meetings held with the Material's Flow Manager, two Warehouse Managers, and a Warehouse parts-put-away employee, to discuss the re-organization of the warehouse and the possibility of freeing up more space. Areas of the warehouse which can be combined or moved were identified in the meeting. The modeled layout was then updated to reflect available space in the warehouse.

On the block layout, areas with similar activities were grouped together, consolidation areas were moved closer to areas with heavier work flow, and aisles were cleared to improve accessibility of parts for picking operations. The overall performance of the changes is measured in terms of closeness of area with heavy workflow, total distance travelled, ease of performing operations, safety and overall organization of warehouse.

The specific areas looked into were the consolidation process, location of workstations, accessibility of parts and safety concerns. As indicated in the Preliminary Analysis section, over 38% of the turnaround time for materials is attributed to these specific areas which comprise picking the parts from their storage locations, navigating through the warehouse and consolidating orders. The approach to these problem areas of interest are detailed below.

4.1 Consolidation Process

Parts picked off storage locations in the picking process are delivered to consolidation areas. Consolidation involves packing a group of parts together into a kit, or number of kits, required by production workers that are ready to be sent out of the warehouse. The size and number of kits required by production varies from order to order.

4.1.1 Wait time for kits

To analyze the consolidation process, the first thing that was done was to figure out what about the process took the longest. The consolidation worker was asked what about the process he thought took the longest. Previous recorded data on the consolidation times for kits was also looked into to see how long it takes parts to arrive to the consolidation area, how long it takes for kits to be completed, and how long kits have to wait for other kits to be completed before being sent out.

4.1.2 When kits are needed

Next, the need for kits by production was investigated. For this, two Production Leads who release some of the orders to the warehouse were asked when they needed kits for their production work, and how they wanted them delivered (i.e. if all at once, one at a time, or some of them). The build sequence of kits was also looked into to see when and how they really need kits within the promised 24-hour turnaround time.

4.2 Location of Work Stations

The work stations of interest include the consolidation area, kit-room, receiving area and sorting area. In investigating the workstations, the layout of the warehouse was obtained from the warehouse manager. A block-format layout was generated and then updated to reflect the recent changes, such as space availability. Each area was then further looked into as detailed below.

4.2.1 Location of Consolidation Area

The first thing done was to map out all the consolidation areas on the layout. The consolidation area for production picks is currently located along an aisle and in-front of a storage location. The consolidation employee was asked the limitations of working in such an area. Also, two warehouse pickers who deliver parts to the consolidation area as well as pick parts from such storage locations were also asked about their limitations.

The amount of workflow from each storage location area where parts are picked from and sent to the consolidation area was also investigated. For this, SAP data for the daily picks, from January to June, was analyzed to obtain the frequency of picks from each storage area. On the layout, the consolidation area was then moved to a different location based on space availability and distance from the picking locations. The rectilinear travel distance from approximately the centroid of each rack-aisle or storage area to the consolidation area was then measured out on the warehouse floor and mapped out on the layout. The total distance pickers have to travel was then calculated by summing up these distances weighted by the amount of workflow from each storage area. This was done for the new and old layouts to see how much travel time is saved.

4.2.2 Kit-Room Evaluation

The function of the kit room is to pick and consolidate special orders that may go to customers as spare parts, or tool upgrades, or may go to production to ship out with a tool, or may go back to stock in anticipation of an order. During the daily observations of the warehouse, the kit-room workstation was backed up with a lot of material all the time. The kit-room had material overflow into the pick-aisles which affects the accessibility of parts during picking.

As a result of these observations, the kit-room employees were questioned about the reason for the backlog, as well as the functions of the kit room. The kit room data management system was also accessed to obtain a list of the open shop orders and their status. Information obtained from the data includes when a shop order was opened, how long it had been open for, why it was still open, what the kit was needed for, and when it was needed. This data was then analyzed to identify the cause of the backlog of material.

4.2.3 Clearing Aisles

Current operations in the warehouse involve picking parts and dropping them off in a consolidation area located in a pick-aisle. This consolidation area takes up space in the aisles and serves as an obstruction to picking from certain storage locations. As indicated in the kit-room evaluation section above, the kit-room also has material overflow to pick-aisles.

The impact of these obstructions in the pick-aisles was investigated. SAP data was analyzed to obtain the frequency of picks from blocked storage locations per day. Two warehouse pickers who pick from these locations were then asked how long it took them to pick parts from such locations. This data was then used to estimate the overall time lost in the warehouse as a result of having these obstructions in the way. This data was also modified to get the time lost on production picks only from the warehouse, by obtaining the percentage of picks from these locations that were for production.

4.2.4 Combine Sorting and Receiving Areas

The sorting and receiving areas were observed daily. Specific observations of interest are the number of times either area was backed up with material, or the workers were not at their desk working. The receiving employee and sorting employee were also informally interviewed separately. Both were asked for their suggestions on improvements to their work area.

4.4 Safety Concerns

During the daily observations of the warehouse operations, fork-lift and cherry-picker operators were monitored for any unsafe actions taken. Other warehouse pedestrians were also monitored. The warehouse manager was also informally interviewed, asking the following questions:

- How often do accidents occur?
- How many in the past year, two years?
- What were the causes of these accidents?
- How were operations in the warehouse affected with respect to lost time and labor force?
- How can the accident reports be accessed?

5. Results and Discussion

This section presents the results of the observations, interviews, and analysis performed, as indicated in the sub-sections of the methodology section.

5.1 Consolidation Process

5.1.1 Wait time for kits

From the discussion with the consolidation worker, he mentioned that the longest part of the consolidation process is waiting for parts to be picked and delivered to the consolidation area, so they can be consolidated into kits, as well as waiting for a group of kits to be consolidated together.

The time to complete a kit (i.e. pick and consolidate parts required for the kit) is the time from when the order for the kit is released in the warehouse for picking to commence, to when the last part required to complete the kit is picked and delivered to the consolidation area. At this point, the kit is considered complete.

The wait time for a kit is the time a complete kit waits for the last kit it is grouped with to be complete, before being sent out to production. Kits are currently grouped into modules. For example, a 90 Module is a group of kits which have codes M900, M901, M902, up to M908. A 70 Module has kit codes M700 up to M705.

Table 5-1 presents the average wait time for kits. This is based on data for one machine, as obtained from SAP. For each kit, it shows when the kit was ordered, when it was released, when it was completed, and the evaluated wait time for the kit. The wait time for a kit is evaluated by subtracting the time a kit is completed from the time the kit that took the longest to complete in the same group (module) was completed.

In the 90 Module for example, M908 was completed last, at 8:09:04am on 3/5/13. M900 which was completed at 7:45:13am on 3/5/13 waited 0.4 hours (from 7:45:13am to 8:09:04am = 0.4hrs), for M908 to be completed.

Similarly, M902 waited 15.05 hours (from 5:06:04pm on 3/4/13 to 8:09:04am in 3/5/13); M904 waited 14.82 hours (from 5:19:51pm on 3/4/13 to 8:09:04am on 3/5/13), and so on. M908 was completed last, so the wait time is zero for this kit.

The average wait time for this module is the average of the wait times for kits in this module.

$$Average\ wait\ time\ for\ 90\ Module\ kits = \frac{0.4 + 15.05 + 14.82 + 0.41 + 10.13 + 0}{6}$$

$$= 6.80\ hours$$

Table 5-1: Average wait time for kits

Kit Code	Ordered		Released		Completed		Wait Time (hrs)	Avg. Wait Time (hrs)
	Date	Time	Date	Time	Date	Time		
M700	3/4/2013	2:22:40 PM	3/4/2013	3:17:47 PM	3/5/2013	8:46:33 AM	0.00	
M703	3/4/2013	2:22:52 PM	3/4/2013	5:01:54 PM	3/4/2013	5:05:56 PM	15.68	5.57
M705	3/4/2013	2:23:08 PM	3/5/2013	7:43:56 AM	3/5/2013	7:45:10 AM	1.02	
M900	3/4/2013	2:23:14 PM	3/4/2013	9:08:42 PM	3/5/2013	7:45:13 AM	0.40	
M902	3/4/2013	2:23:18 PM	3/4/2013	5:03:32 PM	3/4/2013	5:06:04 PM	15.05	
M904	3/4/2013	2:23:29 PM	3/4/2013	3:18:40 PM	3/4/2013	5:19:51 PM	14.82	
M905	3/4/2013	2:23:40 PM	3/4/2013	3:41:59 PM	3/5/2013	7:44:18 AM	0.41	6.80
M906	3/4/2013	2:23:46 PM	3/4/2013	3:38:16 PM	3/4/2013	10:01:22 PM	10.13	
M908	3/4/2013	2:23:57 PM	3/4/2013	3:43:55 PM	3/5/2013	8:09:04 AM	0.00	
MFA0	3/4/2013	2:23:57 PM	3/4/2013	3:35:15 PM	3/4/2013	4:27:42 PM	15.29	
MFA1	3/4/2013	2:24:06 PM	3/4/2013	3:46:23 PM	3/5/2013	7:45:17 AM	0.00	10.60
MFA2	3/4/2013	2:24:08 PM	3/4/2013	3:14:06 PM	3/4/2013	3:15:06 PM	16.50	
MGB0	3/4/2013	2:24:16 PM	3/4/2013	3:31:43 PM	3/4/2013	5:06:04 PM	15.06	
MGB1	3/4/2013	2:24:32 PM	3/4/2013	3:38:22 PM	3/5/2013	8:09:22 AM	0.00	
MGB2	3/4/2013	2:24:34 PM	3/4/2013	3:33:38 PM	3/4/2013	4:29:18 PM	15.67	11.45
MGB3	3/4/2013	2:24:36 PM	3/4/2013	4:59:59 PM	3/4/2013	5:05:47 PM	15.06	
RPES	3/4/2013	2:24:39 PM	3/4/2013	3:36:58 PM	3/4/2013	9:57:35 PM	13.24	6.62
RPMM	3/4/2013	2:24:47 PM	3/4/2013	9:56:36 PM	3/5/2013	11:12:02 AM	0.00	
BFR	3/5/2013	3:15:52 PM	3/5/2013	4:07:37 PM	3/6/2013	10:59:43 AM	0.00	1.62
BFR2	3/5/2013	3:15:54 PM	3/6/2013	7:42:54 AM	3/6/2013	7:44:51 AM	3.25	
1LA1	3/5/2013	6:21:36 AM	3/5/2013	7:30:28 AM	3/5/2013	9:52:28 PM	4.42	
1LA2	3/5/2013	6:21:40 AM	3/5/2013	7:47:42 AM	3/6/2013	1:16:06 AM	1.03	
1LA4	3/5/2013	6:21:38 AM	3/5/2013	8:09:43 AM	3/5/2013	10:57:58 AM	15.33	5.65
1LA7	3/5/2013	6:21:39 AM	3/5/2013	7:40:15 AM	3/5/2013	6:51:23 PM	7.44	
1LA8	3/5/2013	6:21:45 AM	3/5/2013	7:38:51 AM	3/6/2013	2:17:56 AM	0.00	
3LA1	3/11/2013	6:59:28 AM	3/11/2013	10:43:38 AM	3/11/2013	1:13:47 PM	1.33	0.66
3LA2	3/11/2013	6:59:34 AM	3/11/2013	11:54:41 AM	3/11/2013	2:33:30 PM	0.00	
LAUP	3/5/2013	6:21:46 AM	3/5/2013	9:58:29 AM	3/5/2013	10:58:06 AM	14.83	7.42
LAWH	3/5/2013	6:21:49 AM	3/6/2013	1:33:47 AM	3/6/2013	1:48:09 AM	0.00	
							Avg.	6.26

From the table, it is also important to note that there is a wait time or delay period between when an order is placed and when it is released in the warehouse. From discussion with the warehouse employee, this is due to two main reasons. One is they are not aware of what orders correspond to what kit codes. With hundreds of orders made every day at different times, for different machines, these orders have to be individually released in the warehouse, one by one. All the orders get mixed up together, and since the orders are released one by one, there is a delay in when some orders are released versus some others.

In the table for example, some of the kits ordered on 3/4/2013 between 2:22pm and 2:24pm (Kit codes M700 through RPMM) were released individually between 3:14pm and 3:56pm, in no particular sequence. M703, M902 and MGB3 were released about an hour and a half later around 5:00pm, while M900 and MGB3 were released much later around 9:00pm and 10:00pm respectively. Again, it is important to note that the warehouse employee who releases the orders does not know what kits are being released. The orders are individually released, one by one as discussed earlier. There are breaks in-between orders, and some orders get skipped or may accidently not be released. These outstanding orders are realized much later and then released.

The other reason for the delay between the order created and released is that it also depends on the time of the day the orders are created. Orders are typically released at the beginning of the first and second worker-shifts (around 7:00am and 3:30pm). This can be seen in the Released column of the table. Also, in the morning shift (around 7:00am), sales orders are released first, before production orders. Sales orders are handled a little differently and can be accessed separately from production orders. This also contributes to the delay between when production orders are created and released.

Kanburapa's thesis discusses more about when orders should be placed and released [9]. However, the main purpose of presenting this delay information here is to show that the employees who release the orders do not know what the kit codes are for the orders they release. And as such orders are released in no particular sequence. Regardless of the delay time associated with the releasing of the orders, completed kits do not need to wait for other kits they are grouped with to be completed before being sent out. The reason for this is further discussed in the next section, as production have a build sequence for kits.

5.1.2 When kits are needed

As a result of the findings about the wait time of 6 hours for kits, two separate discussions where held with two Production Leads who order kits, one from each of the two main production floor areas where kits are delivered to; the modules-build area and the end-station area.

Both mentioned they order all the kits required for a module about the same time, 24 hours before they are needed. The Ordered column of Table 5-1 confirms this, as all 90 Module kits for example were ordered around 2:23pm. They also mentioned they prefer to have all kits delivered at once, as they do not want workers to be sitting idle waiting for any particular kit, as the workers are quite flexible with the order in which they build the modules. However, they do not need all kits they order at once. Each kit or kit code is comprised of a group of parts required to build or assemble a section of a module.

A kit-build is the build-up or assembly of parts in a kit required for a section of a module. When a kit-build is complete, the workers move on to the next kit of parts. The Production Lead at the modules build area also mentioned that a reason for ordering all the kits at once is to prevent a situation whereby the next kit of parts may not have been delivered to continue build. Also, if something goes wrong during the build of a particular kit of parts, they can sometimes move on to building the next kit of parts, so time may be wasted if that kit is not available.

He also mentioned that the order in which they build kits for a module follows a particular sequence as set by the manufacturing team for optimal labor hours. This sequence for a 90 Module is provided in Table 5-2 below. For example M901 is built first, followed by M902, and so on. The table also presents the time required to build these kits. The data is based on a time study for 6 machines conducted by one of the Production Lead in this area.

Table 5-2: 90 Module Kit Build Sequence

	Kit Code	Description	Build Time (hrs.)
90 Module	M901	Mod Prep	10.5
	M902	Resolving Chamber	3.5
	M903	Elect. Rack & Components	1.8
	M904	Source Chamber & Turbo Pumps	7.2
	M905	Manifolds	2.5
	M906	Liners & Beam Dump	4.0
	M907	Harnessing & Manipulator & N2 Bleed	4.8
	M908	Late Point Options/Specials	0.2
	Total		**34.5**

From the tables, it can be seen that there is an established build-sequence for the kits. These kits require 1 to 10 hours to build, and a module can take up to 35 hours to build. These results, together with the outcome of the discussion with the production leads, show that the kits are really not all needed at the same time. Therefore, there is really no need to send all kits at once. Completed kits do not need to wait for other kits to be complete. Also, production may not need to place orders for kits all at once.

Going back to Table 5-1 for example, M908 was completed last. As a result, kits M900 through M906 waited for M908 before being sent out. M902 waited 15 hours before being sent out.

Meanwhile, as presented in Table 5-2, M902 is needed 10.5 hours (time to build M901) after work on the module is commenced (i.e. the start of the build for M901). M908 is also not needed for up to 34 hours after the build of the module is commenced, as kits M901 through M907 would be assembled during this time. This therefore implies that all the kits are not necessarily needed at the same time. For this example, it is important to note that kits M901, M903 and M907 are not picked from the warehouse, which is why they are not presented in Table 5-1.

5.2 Location of Workstations

5.2.1 Location of Consolidation Area

The results of moving the machine, kit-room, sales and shop orders consolidation areas are presented below. The impact on travel distance was first evaluated, and then more analysis was done to highlight specific benefits of moving the kit-room and machine consolidation away from their current locations.

Figure 5-1 shows the block-layout of the warehouse as it currently is. The storage areas are highlighted with letters and numbers.

Figure 5-2 shows the proposed layout with the consolidation areas brought closer together and moved to the freed up space in the GL storage area. In the warehouse meeting held on July 25, 2013, with the materials flow manager, warehouse manager, and parts-put-away employee, it was mentioned that parts in three GL high-racks, just below VLM-03, were in the process of being consolidated into other racks or put away in empty bins in the VLMs. It was also mentioned that these racks were scheduled to go down in the next couple of weeks.

The sales consolidation area also consists of a single line of 8 pallets on the floor. This area can be shrunk to have two stacked levels by installing a two-level rack that is reachable without a ladder. The outcome of this meeting resulted in the freed up space being utilized by kit room and shop order consolidation area in Figure 5-2.

The impact of these moves with respect to time savings on picking operations is discussed in the next two sections.

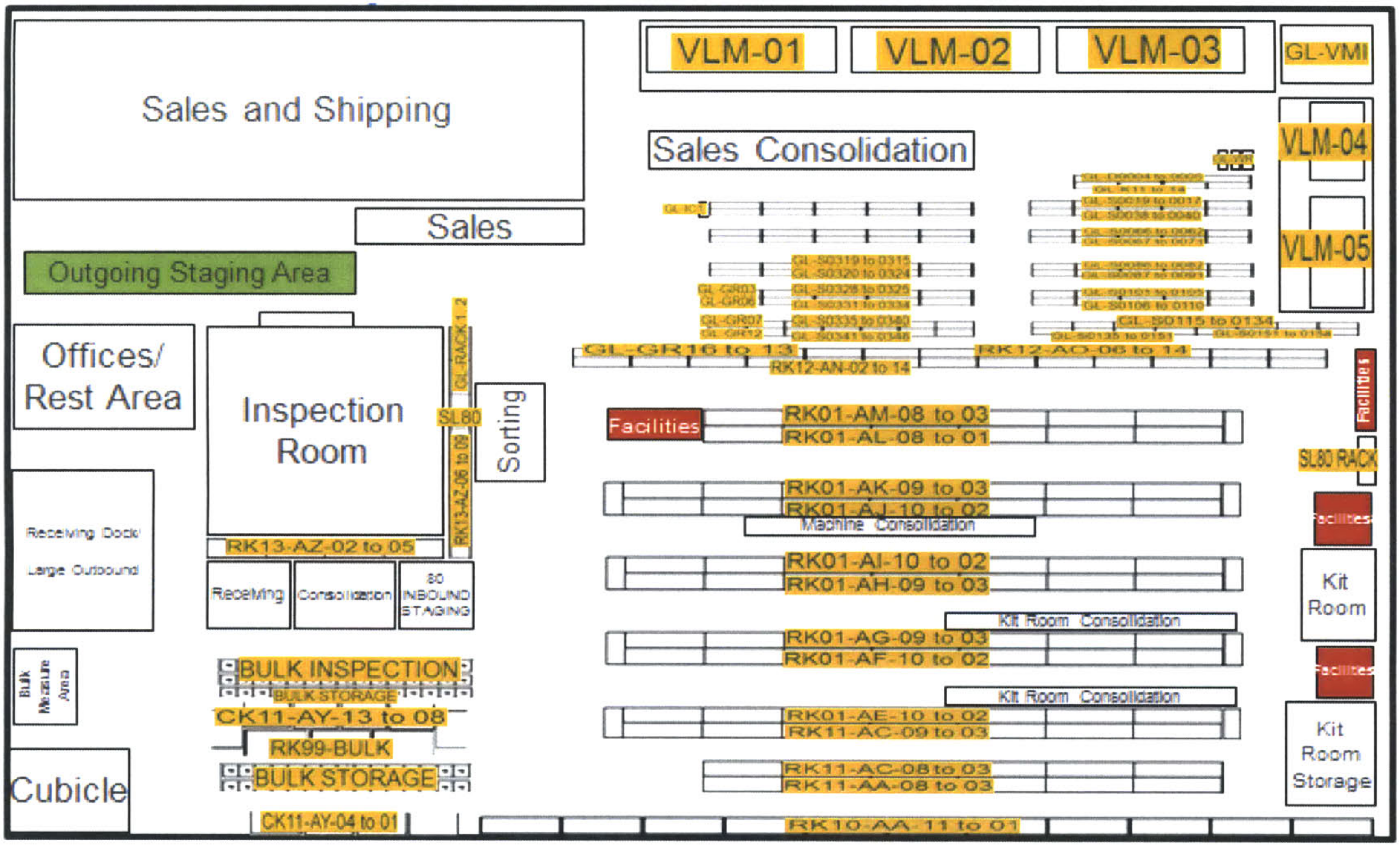

Figure 5-1: Current layout

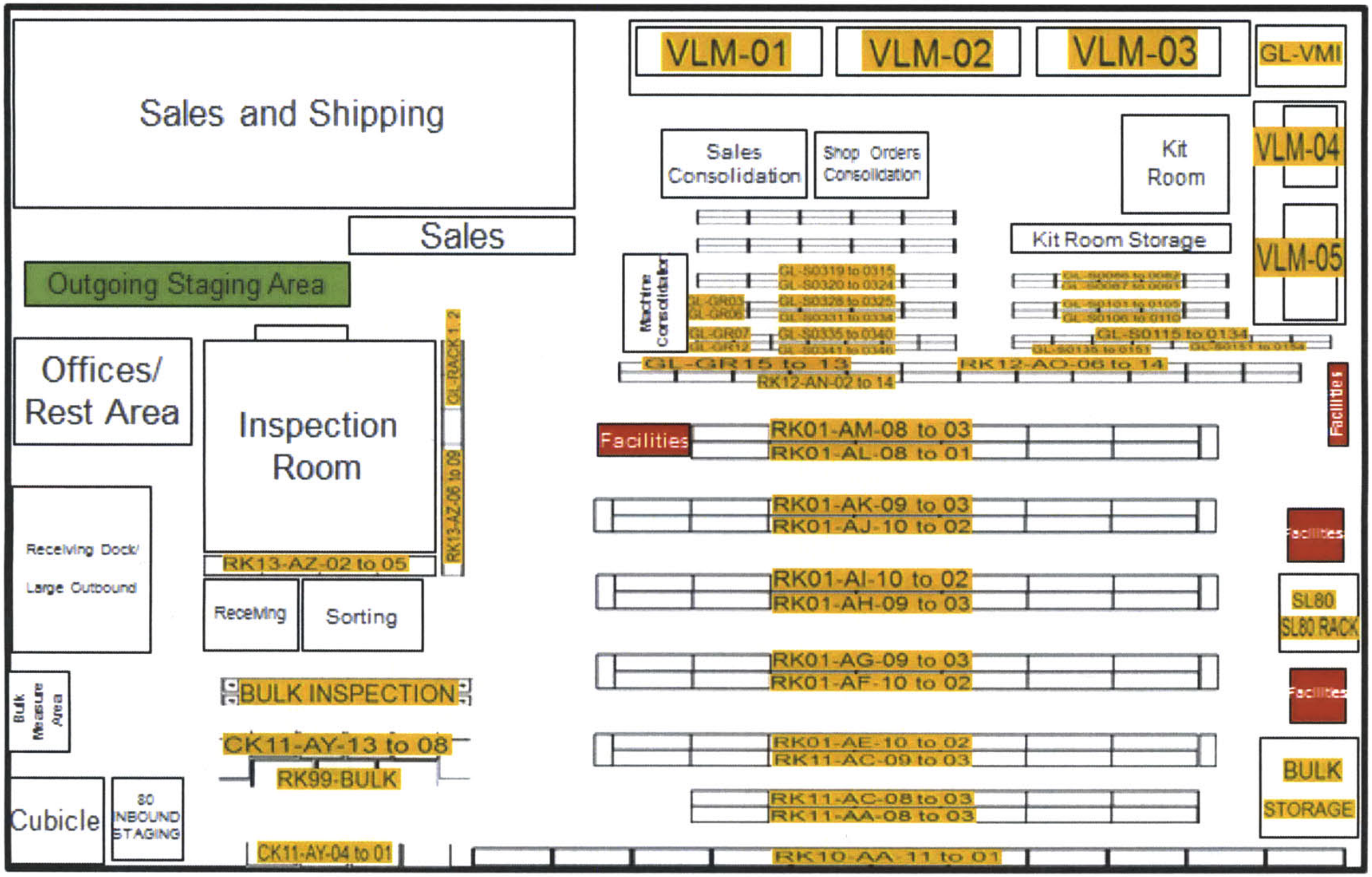

Figure 5-2: Proposed Layout

5.2.2 Kit-Room Evaluation

On July 10, the kit-room data management system was accessed to see the status of kits. 106 open shop orders were found. A kit-room shop order consists of a group of parts required to fulfill an order.

The open shop orders were then further investigated in SAP to obtain information on how long ago these orders were made and their current status (i.e. if the order is waiting for shortages or has been cancelled). Figure 5-3 shows the result of this investigation. It shows the amount of shop orders that have been open for weekly time periods.

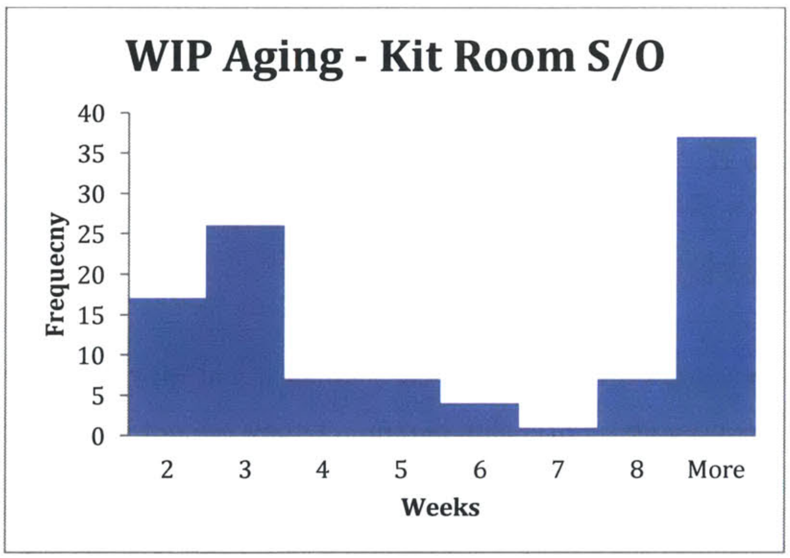

Figure 5-3: Age of Open Shop Orders

From the figure, we see about 45 of the 106 open shop orders have been open for more than 8 weeks. The longest time obtained from this data set was 43 weeks. From the daily observations of the warehouse, the material for these open orders spills over into picking aisles in RK storage area and disrupts picking operations. The impact of this inventory disrupting pick operations is evaluated in the next section (5.2.3 Clearing Aisles).

Further analysis of the data shows that of the 106 open shop orders, 14% were cancelled orders, while the remaining 86% were waiting for shortages.

For orders that get cancelled, each part in that order needs to be individually input back into SAP to indicate that the part is now on-hand and available for any other orders that may need the part. The part is also returned back to its storage location. This process is referred to as breaking back an order and crediting its parts back to SAP. This is a very time consuming operation, and as a result, cancelled orders often sit and wait in the kit-room area to be broken back at a much later time with less amount of workflow in the area. From the data set obtained above, 5 cancelled shop orders were in the area for more than 33 weeks.

Once parts for shop orders are picked and delivered to the kit-room, they are no longer available on-hand for any other orders or operations that may also need the same part. As a result, these parts in the kit-room waiting for long times (either to be broken back or waiting for shortages) represents a significant amount of inventory being held up in the warehouse.

From the discussion with the warehouse manager and kit-room employee, when shop orders are created by ordering personnel, they are not checked for shortages or parts that are not available on-hand in SAP before releasing the orders. The ordering system also does not prevent personnel from releasing order; it however generates a flag on such orders indicating that shortages exist. The system also has a feature which enables ordering personnel to reserve the parts they need for a shop order without actually releasing the orders for the parts to be picked; however, they are unaware of this feature or not trained on how to do this. As a result, shop orders are currently created and released regardless of the presence of shortages.

It was also mentioned that ordering personnel do so in order to secure parts. They would rather wait on shortages in order to prevent a situation where currently available parts later become unavailable, and their customer orders can no longer be fulfilled. For example if an ordering personnel is expecting a customer order based on forecast, and 8 out of 10 parts required to fulfill the order are currently on-hand, the shop order is released, even if the remaining two parts may take an extended period of time to become available. By doing so, those 8 parts are picked and are physically committed to this order in the kit-room, making them unavailable for any other orders.

However if they are able to systematically reserve the parts in the SAP, they can still fulfill their orders about the same time as they would if they physically committed parts in the kit-room blocking pick aisles. As mentioned by the kit-room employee, if all the parts required for a shop order are on-hand, they can be completed within 48 hours of releasing the order.

Since shop orders are still released regardless of the presence of shortages, a backlog of open shop orders and parts is present in the kit-room area. This takes up space in the warehouse and negatively impacts navigation and picking operations as discussed in the next section. The parts in the kit-room also constitute committed inventory which cannot be accessed for other production or business operations if needed.

5.2.3 Clearing Aisles

From the observation of the warehouse layout and operations, a total of five sub-sections from two major storage location areas are often blocked by other parts, so access is limited. These parts include kit-room open shop orders, parts required for machine consolidation, as well as bulk parts in the bulk storage area. These storage areas can be seen in Figure 5-1 behind the machine and kit room consolidation areas, as well as the CK11 storage area where bulk material clog the area. Moving the machine consolidation area, the kit-room, and the bulk materials to the proposed areas identified on Figure 5-2 can affect the warehouse picking times.

SAP data was accessed to obtain warehouse tasks from these storage locations for data from June 1 – July 31 (There are approximately 1200 tasks per day). Table 5-3 below shows the average number of times these locations were accessed per day, and how much time can be saved if these areas were clear for picking operations.

From the discussion with two warehouse pickers who access these locations, they mentioned it takes 5 to 10 minutes to pick from these areas. For this analysis, 5 minutes was used for the RK01 area analysis, and 7.5 minutes for CK and RK area as indicated in the table below. 7.5 minutes was used for the CK and RK area because they involve clearing bulk materials to access parts. Moving bulk parts is expected to take more time.

Table 5-3: Impact of Clearing Aisles

Blocked Storage Locations	Average No. of Times Accessed (per day)	Time to Clear Obstacles (min)	Time Saving (min)
CK-AY-08 to 13	3	7.5	22.5
RK01-AE-03 to 06	6.9	5	34.5
RK01-AG-03 to 06	7.5	5	37.5
RK-01-AJ-04 to 08	4.9	5	24.5
RK99-BULK	4.4	7.5	33
		Total	**152**

The table shows that 152 minutes (~2.5 hours) is saved on the picking time per day. This implies that the last part delivered for that day can be delivered 2.5 hours earlier. On average, parts can therefore be delivered 152/2 = 76 minutes earlier. This is approximately 1.3 hours earlier.

5.2.4 Combining Sorting and Receiving Areas

From the discussion with the primary receiving employee, it was stated and observed that there is not enough room to work. Three warehouse employees have work bench area in a 15 x 15ft receiving work station. Figure 5-4 shows the current layout of this area.

When parts are delivered to the receiving dock, small items are unloaded by these three employees onto a conveyor belt, while the bulk parts are unloaded to the bulk staging area on the floor. These parts are then picked off the conveyor, and scanned into the system at the desk, and tags are applied. These parts are then put back on the conveyor and sent to the sorting area for de-trashing and preparation for put-away.

One of the three employees is not permanently located in the receiving work area. He comes from a building across the warehouse to help out with unloading and checking in the bulk material whenever a truck arrives at the dock. One of the other two employees works both at the receiving work station and the sorting area. He comes over to help out with receiving workload.

From the discussion with the sorting employee, he recommends getting rid of the sorting area and combining it with receiving, as half the time he has no sorting to do and helps out with work in the receiving area. He waits for material sent over from receiving to accumulate from a range of 30minutes to an hour, before sorting all at once, as it takes him less than 20 minutes to complete a heavy delivery off the truck. Figure 5-5 shows the proposed changes whereby the receiving and sorting areas are combined.

A horizontal layout is proposed such that the main employee can still work off the conveyor belt. He now also tags the part after receiving, de-trashes and puts away in the put-away racks. The sorting employee who is now in the receiving area is provided with a bay or rack in the receiving area for receiving and sorting items picked off from the retractable conveyor in batches. This is unlike the current layout where he picks parts from the belt, stages them on the floor next to his desk and keeps performing bending-down operations. With the new layout, he now has a more convenient and ergonomic area to work from.

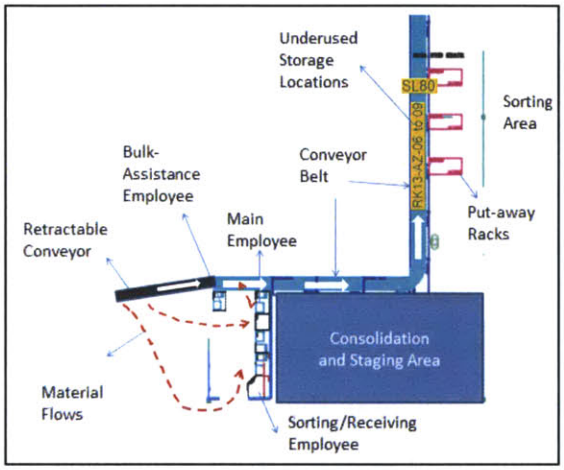

Figure 5-4: Current Layout, Receiving

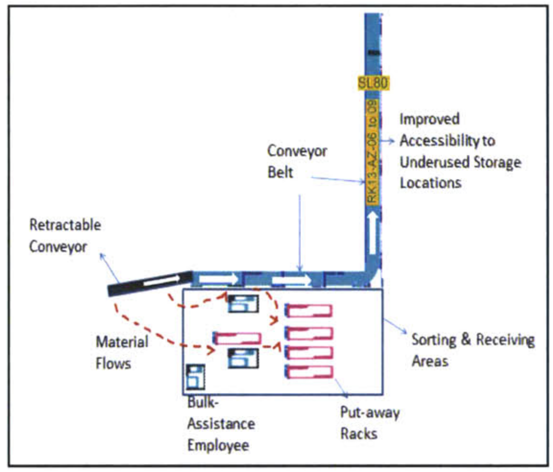

Figure 5-5: Proposed Layout, Receiving

By combining these two areas, space is also cleared up for easy navigation in the warehouse; therefore, safety is enhanced. The storage areas behind the sorting area are now more accessible and can be better utilized. Now that these operations are performed simultaneously and in parallel, it is expected that parts are received faster into the warehouse. This is expected to improve the rate at which cross-dock parts are turned around. However, a time study has not been performed for this.

5.3 Safety Concerns

From the safety discussion held with the warehouse manager, he mentioned accidents do not occur that often in the building. He recalls only one accident in the past two years. This involved a picker who ended up with some bruises after falling during operation of a fork lift, and needed to be checked for about 20 minutes.

He mentioned that when accidents do occur, safety procedures require the accident area be shut down for a period of time for investigation. This period of time ranges from 15 minutes up to an hour. Such area could be an aisle, if it occurred during a picking operation in that aisle. Persons or machine involved in accidents have to be checked. If it is a machine failure, a mechanic typically has to be called in and the machine fixed and tested. This may take up to a day.

The shutdown time or machine servicing time is lost time in performing warehouse operations. In situations where person involved need to be out for a few hours or days the labor force is shifted around to fill-in for affected operation. As a result, the overall labor efficiency of the warehouse efficiency may be slightly decreased. In cases where affected person is out for more than a week, replacement labor needs to be sought. This may take up to a week to get a new hire.

More specific accident report data was asked for, to better analyze their impacts on warehouse operations, but for confidential reasons these could not be provided.

6 Recommendations

Based on the results obtained from the analysis of Varian's current operations in the warehouse, the following are recommendations to help reduce the turnaround time for ordered material.

- SAP/EWM should be updated so the warehouse employee who releases orders in the warehouse can release orders by kit codes.
- Production Leads should prioritize kits by indicating a time needed for kits in SAP/EWM when order is placed.
- The warehouse employee who releases orders should release kits by the time they are needed, not by time they are ordered.
- The consolidation employee should consolidate and send kits immediately after they are completed.
- The machine and kit room consolidation areas should be moved away from the pick-aisles to free space in the GL area.
- The receiving and sorting areas should be combined.
- Excess bulk parts should be moved from the aisles of cantilever and bulk storage racks to the storage rack space freed up from combining the receiving and sorting areas.
- Personnel who order kit-room shop orders should be trained on how to reserve parts on SAP/EWM for shop orders.
- Kit-room shop orders should be released only when all parts are on-hand. Superior authority should be sought for special orders.
- Times should be designated for breaking back and crediting cancelled kit-room shop orders. This can be done once a week.
- The size of the kit-room should be shrunk and moved to the free space in the GL area.
- The floor of the warehouse should be painted to mark off pedestrian walk area and fork-lift or vehicle pathways, as already implemented on the production floor.

7 Impact

The recommendations from this thesis are to be considered in conjunction with the recommendations from Kanburapa's thesis [9] and Surveski's thesis [11].

Surveski's thesis makes recommendations regarding trucking, worker shifts, and part tracking. It suggests adding an additional truck driver that is dedicated to building 80, rearranging first shift workers to come in earlier or later, removing two scan locations for tracking, and adding an additional scan location for tracking [11].

This thesis makes recommendations regarding ordering, consolidation, and where things are located in the warehouse. It suggests that production indicate priority of parts ordered, kits are sent immediately when ready, the location of the sorting station and kit room be moved, and the aisles of the warehouse be kept clear.

Kanburapa's thesis deals with the improvement in order picking system. Recommendations for improvement are made regarding three areas. First, create a system to make picker aware of their task to make sure the parts are left unpicked overnight. Second, resolve the wave releasing issue to be First-In-First-Out to allow continuous picking. Lastly, employ a correlation-based storage assignment to reduce the picker's travel time [9].

The mean lead time is currently 38 hours and the median is 26 hours. Half of the parts are completed in less than 26 hours, but the distribution is skewed right, and some parts take a very long amount of time. Many of the suggestions made eliminate these outliers on the high side. For example, painting the floors for safety reasons will normally not reduce the lead time. However, it will dramatically reduce the time on some of the would-be outliers in the future if it prevents a warehouse shutdown due to safety reasons.

With many of the recommendations made having an impact as illustrated above, it is estimated that the mean time will be much closer to the median of 26 hours. This will be a big improvement already, and some of the following recommendations will further reduce this time.

Table 7-1: Expected Impact

Recommendations	Expected Time Savings
Ship kits as soon as they are ready	6 hours
A signal to show pickers when a part needs to be picked	1.5 hours
Clear the warehouse aisles	1.5 hours
Adding a dedicated truck for building 80 parts	1 hour
Make the warehouse queue first in first out	1 hour
Correlation based storage assignments	1 hour
Remove two tracking scan locations	1 hour
Have a truck run at the end of the day	0.5 hours
	13.5 hours

The above recommendations are predicted to reduce the 26 hour lead time by an additional 13.5 hours. This results in the predicted mean and median lead time being 12.5 hours.

Also, the recommendations on changes to worker shift distribution allow this 12.5 hour lead time to be consistently achieved. This is because it sets up the warehouse so that all parts that are needed for the second shift will be ordered 8 hours before the beginning of the shift and all parts will be delivered on time. For parts needed on first shift, the parts will be ordered 16 hours before first shift starts.

8 Conclusion and Future Work

At Varian, the lead time for parts ordered by production has a mean of 38 hours and a median of 26 hours. While orders are in the process of being filled, it is common for production or the customer to change the parts needed or the schedule. When this happens, the parts are still delivered to production. They then need to go through a time consuming credit process.

The goal set at the start of the project was to reduce this lead time to 8 hours.

To achieve this goal, the team at Varian took a deep dive into the current operations and identified potential areas for improvement. These were then split up among the three team members. Each member learned more about their area and analyzed potential improvements.

The recommendations given to the company include those generated from all three areas. Varian should first tackle some of the high impact recommendations such as having the workers in building 80 ship kits as soon as they are complete. Other critical changes include introducing a signal to show pickers when parts need to be picked, clearing the aisles of the warehouses, and adding a dedicated truck for building 80. The next most important suggestions include changing the warehouse queue to "first in first out", creating correlation based storage assignments, and removing some of the tracking scan locations. Finally based on the results of these changes, an appropriate worker shift distribution should be determined.

The expected impact after all of this is complete is that the lead time will be reduced to 16 hours. The original goal was 8 hours, but this was determined to be unrealistic to achieve in the near future.

In the next few years after these changes have been implemented, there are other areas that could be explored to reduce the lead time past the 16 hours. These include batch size of wave releases, sending parts back while in process, and automatic replenishment in the supermarket.

The batch size of waves is important because a larger batch size increases picking efficiency. On the other hand, a smaller batch size allows the first ordered parts to move through the system quickly. An analysis on the balance between this would be useful.

A way to divert parts that are on their way to production would be valuable as well. This is important because many part orders may currently be canceled while the parts are still physically in the warehouse. However, because there is no way to divert or cancel the order, the parts are still sent to production.

Finally, the inventory of most of the supermarket parts is tracked in SAP. These counts in the system could be used to trigger new orders of parts, rather than a worker having to do this. This improvement would save workers time and allow them to do more important tasks.

Appendix B: Bibliography

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