Managing Preventative Maintenance Activities at Intel Corporation

by
Rebecca Cassler Fearing

Bachelor of Science in Civil Engineering and Engineering & Public Policy,
Carnegie Mellon University (1999).

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Signature of Author________________________________
May 12, 2006
MIT Sloan School of Management
Department of Civil Engineering

Certified by________________________________
Stephen C. Graves
Abraham Siegel Professor of Management

Certified by________________________________
David Simchi-Levi
Professor of Engineering Systems and Civil & Environmental Engineering

Accepted by________________________________
Debbie Berechman
Executive Director, MIT Sloan MBA Program

Accepted by________________________________
Andrew Whittle
Chairman, Department Committee for Graduate Studies
Department of Civil Engineering

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Abstract

The work for this thesis was completed at Intel Corporation in Colorado Springs, Colorado at Fab 23, a semiconductor fabrication facility making flash memory. The project focused on evaluating and managing preventative maintenance activities to improve WIP (Work in Progress) management and cycle time.

Equipment runs a factory, but effective maintenance of that equipment is often overlooked for improvement efforts due to constrained technical resources. However, preventative maintenance (PM) activities can provide process stability and increased throughput if scheduled and executed efficiently.

This thesis evaluates the benefits of coordinating PMs among functional areas and the effectiveness of existing PM practices at a 24 hours per day, 7 days per week facility. Using a WIP model, I show that wait times can be significantly reduced by scheduling PMs on sequential tools at the same time, so WIP only waits once for PMs. Additionally, the goal of an effective maintenance team is to spend more scheduled time maintaining equipment and less time doing unscheduled repairs. A base line of PM performance at Fab 23 is completed showing that they have opportunities to improve their PM processes by learning from other Intel facilities and implementing off-line repairs.

Thesis Advisors:
Stephen C. Graves
Abraham Siegel Professor of Management, Sloan School of Management

David Simchi-Levi
Professor of Engineering Systems and Civil & Environmental Engineering, Department of Civil and Environmental Engineering

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Chapter 1: Introduction

1.1 Program Background

This thesis is the result of a six-month internship at Intel Corporation's Fab 23 (F23) operation in Colorado Springs, Colorado. Intel Corporation created the project with the purpose of improving the operation and completing the thesis requirements for the MIT Leaders for Manufacturing (LFM) program. Intel is a sponsor company for LFM and regularly utilizes LFM students in this capacity. In this case, F23 was facing WIP management and cycle time challenges and sought LFM contributions to their improvement efforts.

1.2 Problem Statement

After evaluating the initial state of Fab 23's operations and discussing them with Intel and MIT advisors, the following problem statement clarified which operational challenges this thesis project would address:

- F23 has a long cycle time relative to its flash memory competitors.
- WIP flow is not balanced through the fab, which results in bottlenecks, underutilization and increased cycle time.
- A major obstacle to balancing WIP flow is equipment downtime due to required preventative maintenance.

1.3 Thesis Overview

This thesis will describe the project background and activities in detail. The following chapters will be used to document findings and recommendations:

Chapter 2: Intel and Industry Overview provides an overview of the corporate and industry environment of which F23 is a part.

Chapter 3: Fab 23 Environment discusses the initial state of the F23 organization, operation and initiatives.

Chapter 4: Planning Preventative Maintenance Activities outlines how a WIP model was used to justify operational guidelines for coordinating preventative maintenance activities.

Chapter 5: Evaluating Current Preventative Maintenance Activities explores the requirements and effectiveness of current preventative maintenance activities and prioritizes improvement opportunities.

Chapter 6: Observations and Recommendations reviews project findings and makes recommendations for F23 improvements.

Chapter 2: Intel and Industry Background

This chapter provides the background necessary to understand the corporate, factory and industry situations that impact the F23 WIP management challenges at hand.

2.1 Intel Corporation Background

Intel Corporation was founded in 1968 to manufacture semiconductors including **INT**egrated **EL**ectronics, hence the name Intel. Initially, Intel's development and production efforts were focused on memory products. However, for the past 15 years, this Fortune 100 company has developed significant brand recognition and revenue for their microprocessors including the Pentium line of products.

Intel currently operates 11 fabrication facilities (fabs) worldwide that are managed by the Fabrication Sort Management (FSM) organization. Internally, the fabs compete against each other for production volumes, new equipment processes and new products. This competition can be quite fierce especially as the company transfers from 200mm wafers to more cost effective 300mm wafers. All locations vie for 300mm processes, which have long term viability. Fabs with only 200mm capability are highly motivated to demonstrate operational excellence that qualifies them for the transition to 300mm. Without plans for 300mm production, a fab is considered "at risk" for eventual shutdown.

In addition to internal competition, Intel has high performance expectations that are formally communicated. Failure to meet formal goals and expectations is generally unacceptable. This cultural mainstay in conjunction with internal competition has fostered a risk adverse environment. Therefore, there is little incentive to make aggressive commitments to the corporate FSM team. Rather, fabs are more inclined to have two sets of goals: the external FSM commitments and the internal goals. If an internal, aggressive goal is met, then the fab shares their success externally. This mentality may minimize the sharing of incremental improvements and failures that hinders the growth and improvement of their company wide Best Known Methods (BKMs).

2.2 Flash Memory Industry Background

Intel invented Flash memory in 1984 and launched its NOR (not-or) flash sales in 1988 (Gardner, 2005). Since then, Intel's multilevel cell technology that stores "more than one logical bit in each physical memory cell...has contributed to a 200-fold increase in flash memory density" (Fazio, 2001). This high-capacity flash memory "retains its data when power is turned off" (American Heritage Dictionary, 2000), which is an advantage over random access memory (RAM) that does not retain data without power. This feature makes flash very compatible with small electronics such as cell phones because although batteries may die, the user still needs all of their stored phone numbers once the device has been recharged. Intel's flash memory is used in a variety of products including Motorola and NEC cell phones, Palm and Dell personal digital assistants, Fuji digital cameras and GM's On-Star vehicle communication system.

Currently the flash memory market is comprised of NOR and NAND (not-and) memory. NAND memory was created after NOR as a lower cost, higher density alternative. However, NAND only allows sequential data access, as opposed to NOR which has faster, random data access. Intel only produces NOR and as of May 2005, Intel has the number one market share for NOR flash products (Burke, 2005).

However there has been a fierce market share competition in the flash industry in recent years. In 2003, Samsung took the market share lead with 21% of the market while Intel held on to 15%. In 2004, the President of Samsung's semiconductor business, Hwang Chang Gyu "boasted about Samsung's 80% revenue growth in semiconductors in the first half of 2004—noting that the figure was nearly four times Intel's growth" (Ihlwan, 2004). At that time, Intel was also losing flash market share to AMD (Taylor, 2005). However in late 2004, Intel fought to regain market share which resulted in a 30% reduction in flash prices. Intel absorbed the decreased revenue easily while AMD was severely hurt as flash products represent almost 50% of their revenue (Edwards, 2005).

Despite Intel's success in flash, it still faces major challenges. For example, Intel's long manufacturing cycle time does not allow them tremendous flexibility for changing customer requests, and they are not profitable in this market (Vogelstein, 2004). To contrast, Samsung is profitable, and their approximately 30 day cycle time (Leachman, 2002) affords them a much quicker response time in a volatile, commodity market.

From a flash industry perspective, Intel is successful, but not stable due to unpredictable market conditions. This position provides a challenging environment for fab management and manufacturing technicians at Intel's Fab 23, one of three facilities making Intel's flash products.

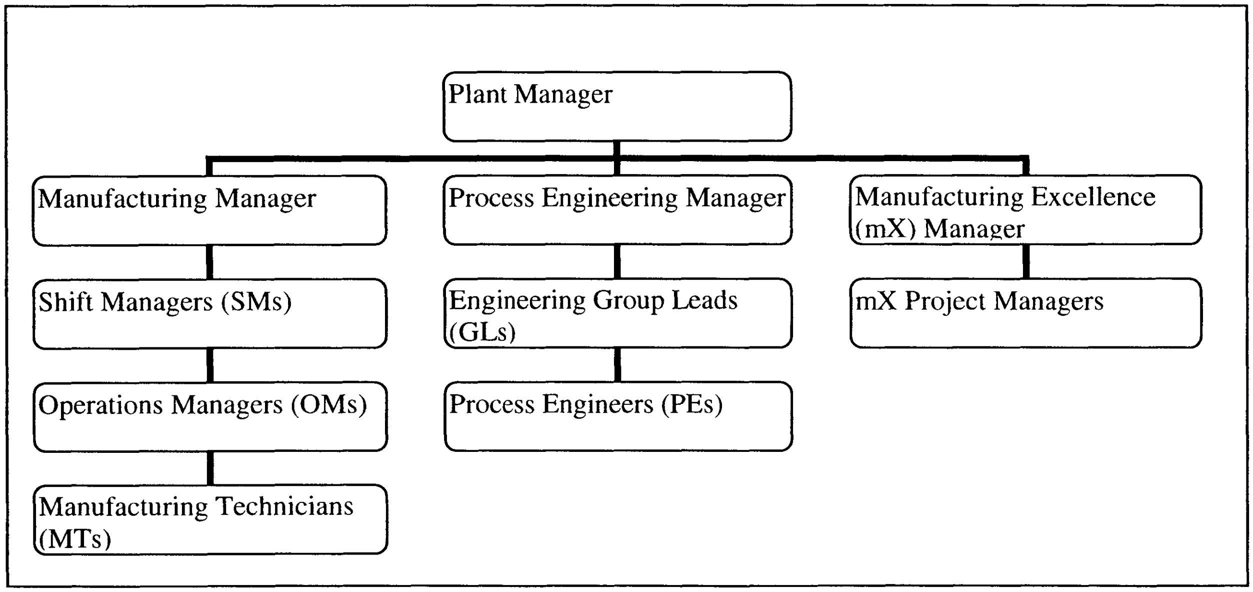
Chapter 3: Fab 23 Environment

Fab 23 (F23) is located in Colorado Springs, Colorado at a former military semiconductor facility. Intel began manufacturing flash memory devices at F23 in March 2001 when the high tech industry was experiencing a significant downturn. In its first two years of operations, the facility had two substantial layoffs reducing staffing from approximately 1100 employees to approximately 800 employees. Since then, the fab has been considered for shut down due to flash memory industry fluctuations and low volumes which cannot utilize economies of scale. This short, yet tumultuous, history has left the employees with lingering feelings of insecurity.

3.1 Current Organization

F23 makes flash memory in "lots" of 25 wafers at their 24 hours per day, 7 days per week operation using four shifts of 12 hours per shift. The facility includes a Plant Manager who reports into the corporate FSM office. The Plant Manager has a staff which includes many support organizations most notably a Manufacturing Manager, a Process Engineering Manager and a Manufacturing Excellence (mX) Manager as shown in Figure 1: F23 Org Chart.

Figure 1: F23 Org Chart



The Manufacturing Manager is responsible for the manufacturing operations. Manufacturing Technicians (MTs) comprise the direct labor force, which processes wafers on all four shifts, and report up through the Manufacturing Manager. The Process Engineering Manager's organization includes Process Engineers (PEs) who are responsible for equipment in all functional areas in the fab. The MTs and PEs must work together to ensure equipment availability and the achievement of production goals.

The Manufacturing Excellence (mX) Manager leads F23's lean manufacturing and waste minimization efforts. The position was created two years ago and includes project managers who devote all of their time to improvement activities as opposed to daily operational issues. The mX manager has also hosted two previous MIT Leaders for Manufacturing interns to assist in waste minimization and WIP management activities.

The F23 organization faced uncertainty in the Spring of 2005, as the corporate Factory Sort Management (FSM) team determined Intel's long range plan which included a roadmap of production assignments for each fab. F23 managers felt the churn from this process and wondered what F23's assignments would be. At the same time, the fab was struggling to meet production goals for a new product. Transitioning equipment and employees to the new product caused process instability and firefighting throughout the organization. Initially, the MTs did not sense the urgency of the issues facing F23 as they continued habits acquired during slow production at the end of 2004.

Eventually, MTs and other employees sensed management's stress and were relieved when the plant manager helped focus the organization on their current goals. The management team instituted a daily production meeting including engineering, quality and production control to ensure engagement from these teams. Production goals were met due to this increased focus. Additionally, FSM finished the long range plan which awarded F23 300mm technology, a positive signal that the fab now had long term viability.

3.2 Corporate Cycle Time Goal

In early 2005, F23 had a long cycle time within the flash memory industry. Although the manufacturing team was extraordinarily focused on safety and quality, they had minimal interest in cycle time reductions until FSM set a cycle time goal. Then, F23's goal was to improve fab cycle time to world class levels by the end of 2006.

To achieve the cycle time goal, F23 would have to drive waste out of their manufacturing process. This was the perfect opportunity to use mX waste elimination principles. A previous LFM intern had worked with the mX team to create a Work In Process (WIP) management system called Ideal Production Quantities, IPQs (Connally, 2005). IPQs were based off of a Samsung case study which indicated that Samsung's cycle time was best in class due to their WIP management techniques (Leachman, 2002).

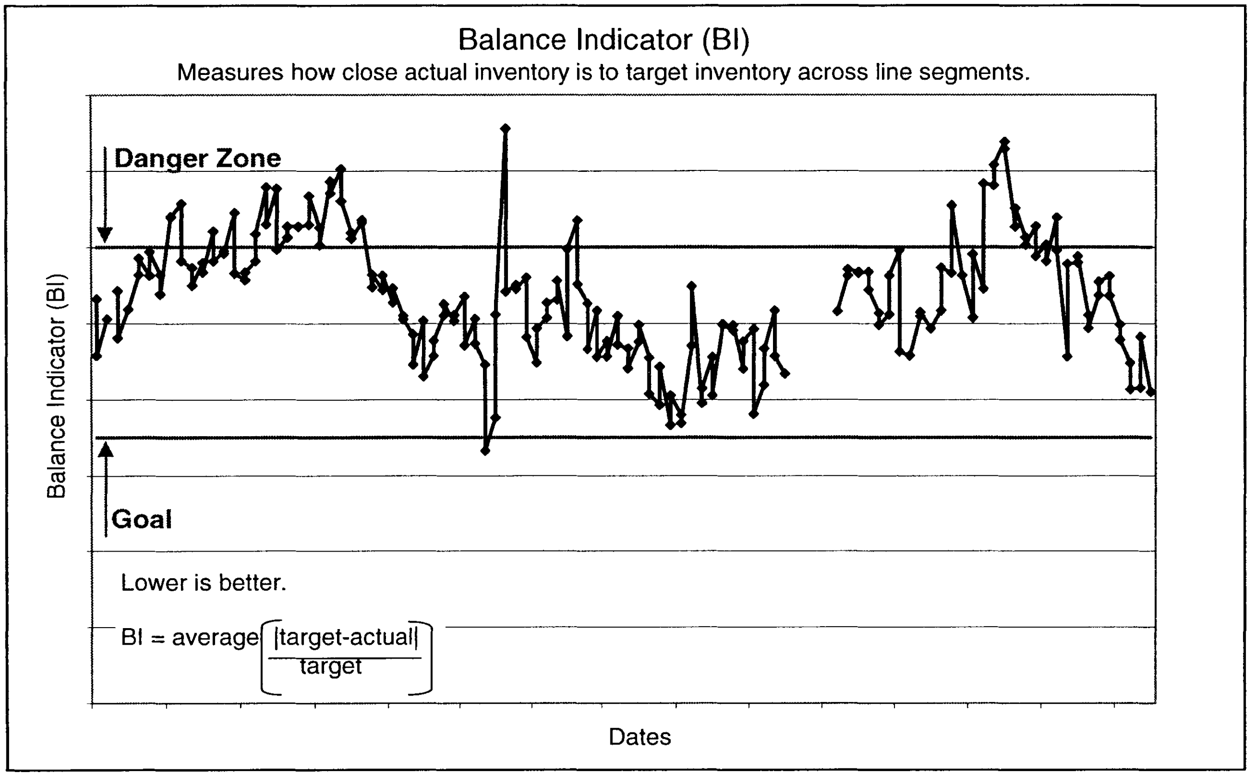
The premise behind IPQs was that if WIP could be controlled throughout the line, process bottlenecks and under-utilization would be minimized. This would permit more balanced (stable) production flow throughout the fab, which then would allow Intel to reduce WIP and cycle time. To measure the line balance after the IPQ system was implemented, a Balance Indicator (BI) metric was instituted and adopted by F23's Operations Steering Committee. For each segment of the line, the IPQ system created a target inventory corresponding to the planned cycle time for the segment. The BI measures the difference between the target inventories and actual inventories across line segments as follows:

$$\text{Balance Indicator (BI)} = \frac{\sum_{i=1}^{n} \left(\frac{\left| \text{target inventory}_i - \text{actual inventory}_i \right|}{\text{target inventory}_i} \right)}{n}$$

where n = total number of segments in line.

When the BI = 0, the line would be balanced in that the actual WIP inventory matched the target. Therefore, the goal was to reduce BI by executing to the IPQ system. BI was tracked for several months as shown in Figure 2: Balance Indicator Tracking.

Figure 2: Balance Indicator Tracking



Whenever the Balance Indicator spiked into the "Danger Zone" on the graph, this was attributed to significant equipment downtime, which could not be remedied by a WIP management system. It became clear that F23 needed to minimize their equipment downtime to provide the process stability required to balance the line and reduce cycle time. Initially, there was no focused effort on downtime which consumed up to 25-30% of capacity on critical equipment.

3.3 High Precision Maintenance Team

F23 staff estimated that a 15-20% increase in capacity could be gained through equipment reliability improvements. This expanded capacity would also provide a corresponding improvement in cycle time. To realize these potential gains, F23 created a High Precision Maintenance (HPM) team. The HPM charter focused on cycle time and included the goal to be the best maintenance organization in the world by end of 2006. In summary, the team had one main objective with five details on how to accomplish their goal:

Team Objective

- **Cycle Time**. To improve cycle time, we need consistently high tool availability.

How to Accomplish Objective

- **Maintenance, not Repair**. Focus on effective maintenance to reduce failures; spend 90% of time on planned maintenance, 10% on unplanned repair.
- **Standardization**. Care for tools by performing PMs exactly according to procedures.
- **Cleanliness**. Keep machines clean and defect free.
- **Measurement**. Track improvements by properly logging downtime including details of what happened and why it happened.
- **Continuous Improvement**. Revise PMs to address root causes of machine failures.

Seven high profile tool sets were the focus of HPM improvement efforts. Engineers and technicians for each tool set embarked on a long-term task of following through the team objective. To contribute to the HPM effort, this project focused on evaluating current preventative maintenance (PM) practices including their scheduling, time requirements and effectiveness. These topics will be addressed in the following chapters.

Chapter 4: Planning Preventative Maintenance Activities

This project's primary focus was preventative maintenance activities. Preventative maintenance (PM) is scheduled downtime used to refurbish and recondition equipment to prevent failures. F23's equipment specifications required that prescribed PM tasks be completed within a given time-based or wafer-based window, generally a period of several days. Initially, the F23 operation had virtually no coordination of PM activities in a set of the same tools or across sequential process steps. The challenge at hand was to find the best way to schedule the PMs to maximize F23's throughput and minimize unnecessary queue time.

4.1 Current Preventative Maintenance Activities

In a 24 hours per day, 7 days per week operation, downtime from PMs cannot be recovered and is essentially lost capacity. At F23, sophisticated semiconductor equipment requires PMs which can take from 30 minutes to 72 hours. This time includes value added maintenance work and re-qualification procedures. Maintenance work includes disassembling part of the tool to remove substance build up, replace valves and seals and secure electrical and chemical feeds. After maintenance tasks, re-qualifications are completed to ensure the machine is running properly. This involves calibration activities and reviewing machine diagnostics for which the time requirements is not negligible.

F23 unofficially prefers to minimize re-qualifications due to their non-value added and time consuming nature. For example, they perform two different PMs on the same tool at the same time to have only one re-qualification instead of two. This practice poses a dilemma. It is initially unclear if this helps the factory by reducing total downtime or if it hurts because a tool is down for one long block of time instead of two shorter periods. The two shorter periods result in more total downtime but provide an opportunity to process WIP between PMs and have a more continuous flow.

F23 often has multiple tools in the same family, which all require PM work. Typically manufacturing technicians (MTs) review what PMs are due in their functional area in the next day and start the PMs close to the deadline. However, this tactical approach does not view the family of tools as a system in which PMs should be coordinated. With this approach more than one tool could be down for PM which can significantly reduce the tool set's capacity.

Sequential process steps on different equipment can be viewed as a system as well. F23 appreciates that processes upstream and downstream from a PM are interrelated. However, in a series of steps, they do not discuss when PMs are due on different tool sets or have a methodology to optimally schedule PMs.

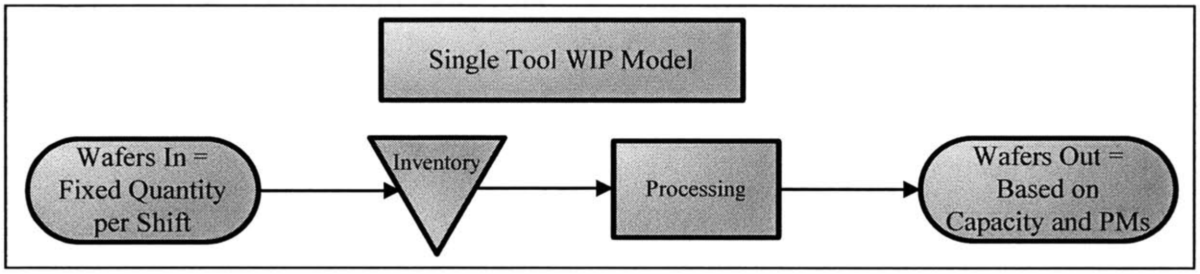
There is a temptation to wait until the last moment to do a PM because the operation needs to focus on running wafers. But, not scheduling PMs strategically can be very detrimental to wafer processing. Wafers may unnecessarily wait for PMs multiple times throughout the production process. For example, it may not make sense to process inventory out of an area if it will only wait downstream because the next tool is down for PMs. Given a five day window to complete a PM, it may make sense to do it early in coordination with a downstream tool so that work in progress (WIP) only has to wait for PMs once, as opposed to twice. F23's tactical approach impairs their ability to expedite wafers through the fab and reliably meet output goals because there is too much stop-and-go WIP flow as opposed to a steady flow.

Currently there is minimal strategic thinking in scheduling and executing PMs throughout the fab. Time consuming PMs can significantly impact WIP flow and cause WIP to accumulate in front of equipment during PMs. This WIP accumulation increases the queue time, reduces value-added activities and increases variability in WIP flow. F23 has not evaluated their scheduling practices or documented procedures for PM scheduling. This investigation sought to quantitatively justify why PMs should be coordinated and guide the operation in effective coordination which maximizes output and minimizes impacts to WIP flow.

4.2 Single Tool WIP Model

The objective of this exercise was to justify PM coordination quantitatively by evaluating a variety of PM scheduling scenarios. Scenarios represented different ways to schedule and execute PMs to maximize fab output and minimize WIP waiting to be processed. To evaluate such PM scenarios on one tool, I made a deterministic WIP model. Using data provided by engineers, manufacturing technicians and equipment specifications, the model evaluated WIP accumulation and output on a shift by shift basis based on what PMs were occurring at what times. Figure 3: Single Tool WIP Model shows a high level overview of the model.

Figure 3: Single Tool WIP Model



Based on fab goals, we assume that a fixed quantity of wafers arrive at the tool on each shift. The wafers wait in inventory until the tool can process them. The number of wafers out of the tool is based on tool capacity and whether a PM occurred during that shift. When a PM starts, the process capacity of the tool is appropriately decreased (for example, if a PM consumes 50% of capacity, the tool can only produce 50% of its normal output) resulting in WIP accumulation in front of the tool and reduced tool output. When a PM is completed, the capacity of the tool returns to its full level, and the tool begins to process the accumulated WIP.

The model used a variety of inputs provided by actual performance data to reflect tool operations and calculated waiting WIP and processed WIP from the tool. Details of the model are as follows:

Category	**Detail**
Scenario / Example	One tool has two different PMs due in one week. Each PM can be started independently on any of the 14 shifts that week. How should they be scheduled?
Tool Specific Inputs (provided by engineering and manufacturing data)	1) Average starting WIP for the tool 2) Capacity for the tool 3) Capacity consumed by PM activity 4) Weekly fab demand, which indicated how many wafers would arrive at the tool on each shift
Decision Variables	The start times of each PM served as decision variables. Each of the two PMs could be started on any shift during the week-long window.
Constraints	Each PM must be started exactly one time.
Objective Function	1) Maximize overall output 2) Minimize WIP waiting in inventory at the tool
Outputs	1) Total output over the evaluation period 2) Total WIP waiting over the evaluation period

This model was utilized for a specific tool set using actual, not theoretical, inputs to provide outputs reflective of the manufacturing operation. Inputs could easily be modified to re-run the model for other tool sets.

Fundamentally, there are two different options for scheduling the PMs on one tool:

- Option 1: Complete the PMs at the same time which requires re-qualifying the tool once, but generates one large WIP bubble (see 4.1 Current Preventative Maintenance for more information on re-qualification).
- Option 2: Space out PMs (i.e. put as much time as allowable between the PM activities) which requires re-qualifying the tool twice, but allows the operation to process WIP between PM activities.

At F23, manufacturing technicians and engineers generally prefer to do both PMs at the same time for this tool because they only disrupt the tool and gather the appropriate PM supplies once. However, there had been no evaluation of if this was the best alternative.

For this tool, the model was run through many scenarios (i.e. starting both PMs at different times during the week) to find an "optimal" schedule which maximized output and minimized waiting. The single tool WIP model results for scheduling Options 1 and 2 above were remarkably similar. For both options, the same time period was chosen for evaluation which allowed both options to work through all waiting WIP. When WIP processed through the tool was maximized and equivalent for both options, the WIP waiting at the tool was evaluated. When the PMs were spaced out (Option 2), 3% more WIP waited over the evaluation period compared to the option of completing the PMs at the same time (Option 1). Although Option 1 was preferable based strictly on the objective of minimizing waiting, an additional 3% waiting quantity was nearly negligible. Thus, there was not a clearly preferable option between the two. Upon further thought, the appropriate scheduling option should be chosen based on the conditions and needs of the fab.

Situations when Option 1: completing PMs at the same time is the better option:

- The tool has significantly extra capacity to quickly recover after PM once the tool starts processing WIP.
- There is another tool in the same tool set that will process WIP while the PM is in progress.
- The downstream tool has an inventory buffer that will feed it through the PM period.

Situations when Option 2: spacing out PMs is the better option:

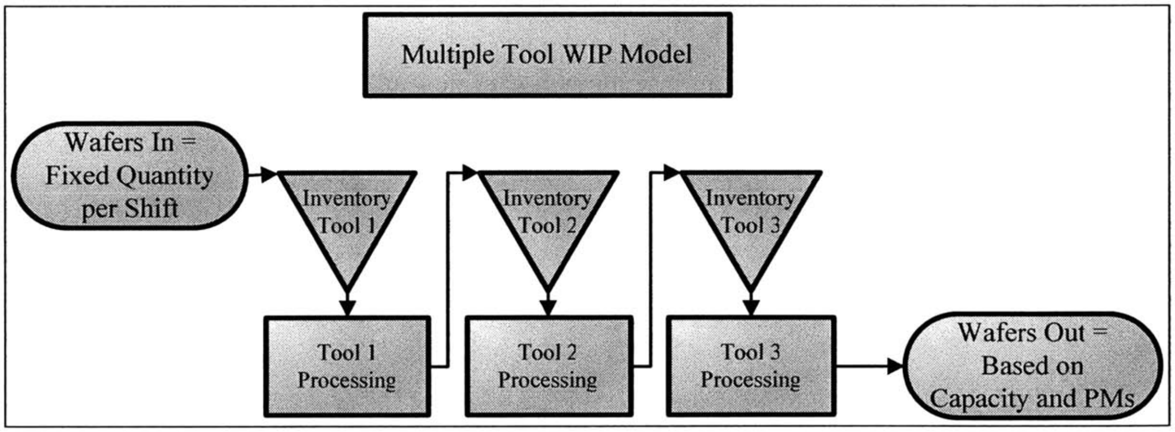
- The tool will not recover from WIP buildup quickly which creates unnecessary waiting.
- The fab wants to minimize the variability in WIP flow.
- The downstream tool has a limited inventory buffer and will starve during the PM.
- The downstream tool is a critical resource whose utilization should be maximized.

After recognizing that optimizing PM scheduling requires a view of several process steps rather than one entity, the WIP model was altered to evaluate three sequential tools.

4.3 Multiple Tool WIP Model

The multiple tool WIP model was created to evaluate three specific sequential tools and was based on the methodology of the single tool WIP model. The inputs, decision variables, constraints, objective function and outputs were the same for the multiple tool model. However, inputs were required from three different, sequential tools instead of just one. Operational data was gathered for three sequential tools by meeting with engineers and manufacturing technicians. For this model, the high level view is shown in Figure 4: Multiple Tool WIP Model.

Figure 4: Multiple Tool WIP Model



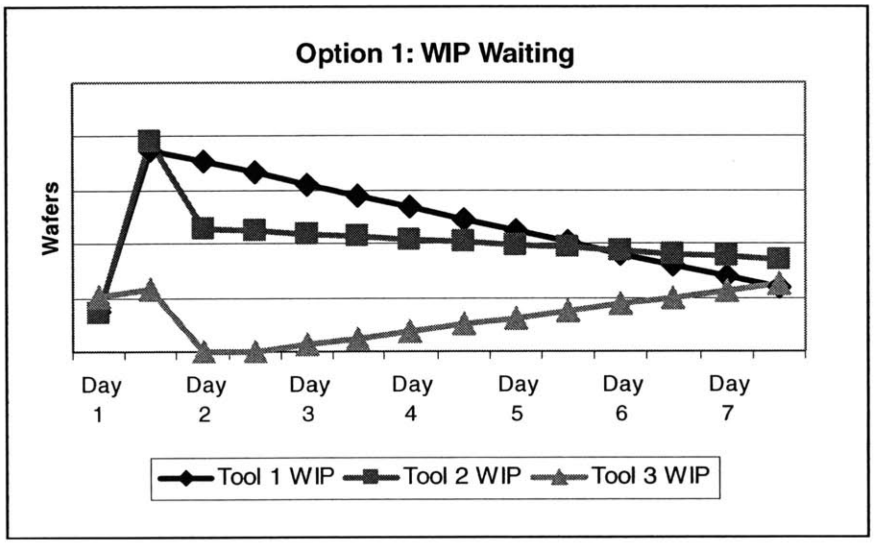
A fixed quantity of wafers arrive at Tool 1 on each shift based on the fab's output goals. The wafers wait in Tool 1 inventory until Tool 1 can process them. Then they move into Tool 2's inventory and processing, then Tool 3's inventory and processing. Finally, the wafers are processed out of the system based on capacity and PM schedule of the tools. As seen in the Single Tool WIP model, when a PM begins on a tool, its capacity is appropriately decreased (for example, reduced to 0 wafers per shift when 100% of capacity is consumed) through the duration of the PM while WIP accumulates in front of the tool, and tool output is decreased or ceased. Scheduling scenarios for this model are particularly interesting as WIP can accumulate or dwindle at each of the three steps. The purpose of evaluating these options was to determine the best way to schedule PMs by maximizing system throughput and minimizing system waiting.

Consider the scenario in which Tool 1 and Tool 2 both have PMs due in the same week. Fundamentally, there are three different options for scheduling the PMs on the two tools:

- Option 1: Start PMs at the same time.
- Option 2: Space out PMs.
- Option 3: Complete PMs sequentially; complete the PM on Tool 1, then start the PM on Tool 2.

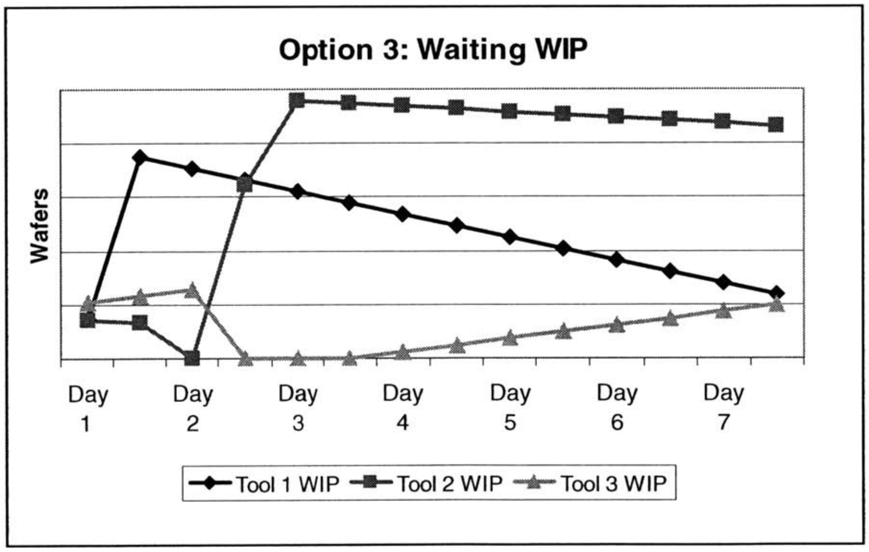
The objective is to schedule PMs in a manner that maximizes processed WIP and minimizes waiting WIP over the evaluation period. Although PMs are scheduled on only Tool 1 and Tool 2, the model included Tool 3 to view what happened to its output for each scheduling option. For example, Tool 3 may have been starved which results in more time required to process a certain quantity of WIP through the system. By design, the scheduling options were compared over a time period that yielded nearly identical quantities of processed WIP. The model was run for a variety of scenarios (i.e. starting PM at different times during the week) to determine the optimal PM schedule for the series of tools. The result showed the variability in waiting WIP among the scheduling options. Figure 5: WIP Waiting for Option 1: Start PMs at the Same Time shows PMs starting at Tool 1 and Tool 2 at the same time.

Figure 5: WIP Waiting for Option 1: Start PMs at the Same Time



Notice that WIP builds at Tool 1 and Tool 2 at the same time on Day 1 when PMs are started, and that waiting WIP starts to decrease on both machines during Day 2. Both machines begin their recovery from the WIP buildup at the same time eliminating the opportunity for WIP to wait twice. In contrast, Figure 6: WIP Waiting for Option 3: Complete PMs Sequentially shows a different picture.

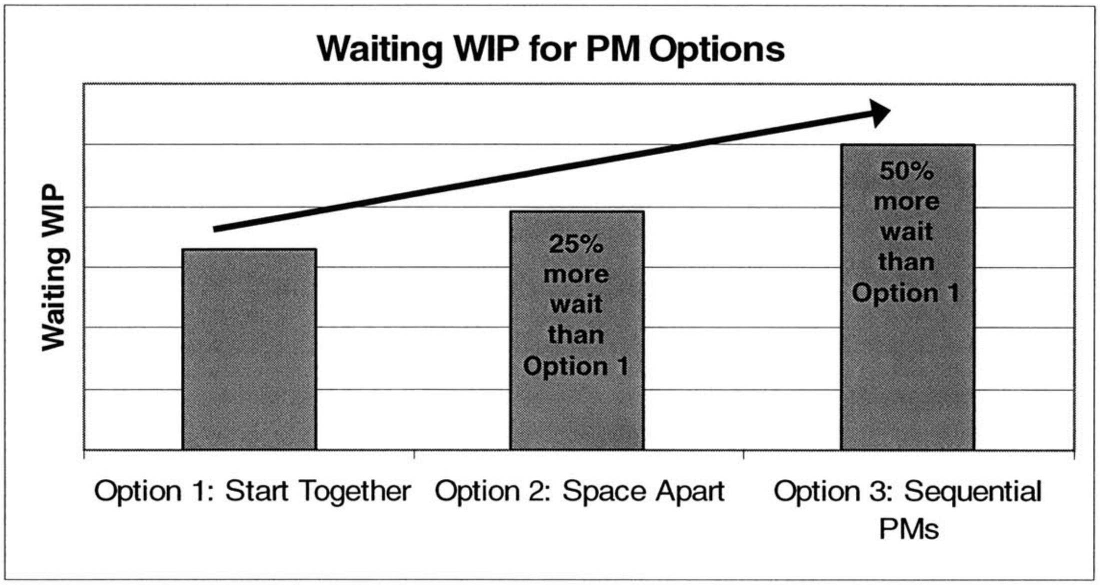
Figure 6: WIP Waiting for Option 3: Complete PMs Sequentially



Tool 1 starts a PM on Day 1. On Day 2, Tool 1 completes the PM and starts processing WIP. Then, Tool 2 starts a PM during the second shift of Day 2. The WIP waiting for

Tool 2 is significantly higher for a longer period of time in this scenario versus Option 1 because WIP waits twice, which allows more wafers into the queue. Figure 7: Quantity of WIP Waiting for Preventative Maintenance Options highlights the differences in waiting WIP levels for the scheduling scenarios.

Figure 7: Quantity of WIP Waiting for Preventative Maintenance Options



Option 1: starting the PMs at the same time is clearly the best option as it minimizes the quantity of WIP waiting over the evaluation period. Operationally, this scenario means that one WIP bubble is built in front of the first process step during the PM execution period. By the end of Tool 1 and Tool 2's PMs, Tool 3 is running out of work. Luckily, both Tool 1 and Tool 2 are able to send work downstream to avoid starving Tool 3. In this case, the tools have been viewed as a system and are scheduled optimally to maximize output and minimize waiting. However, executing this option by starting the PMs together requires the most coordination among process areas. F23 does not have communication channels at manufacturing technician levels or guidelines for such coordination.

Options 2 and 3, which require less coordination, yield 25-50% more waiting WIP and more waste in the fab. Operationally, they both cause WIP bubbles to build in front of multiple tools at multiple times, as opposed to waiting for one tool at one time. This introduces unnecessary WIP imbalance and variability in the fab because there is not a steady flow of WIP. Without a steady flow of WIP, downstream tools are starved and underutilized. Then once they receive WIP, they may build a queue because the incoming WIP is greater than their capacity. The F23 operation is performing in a range between Option 2 and 3; they are not in the worst case scenario, but they are not coordinating WIP among process areas. Currently, upstream tools start PMs without notification. Downstream tools are underutilized or starved during Tool 1's PM. When WIP does flow downstream, other PMs are due which causes WIP bubbles to build and further underutilization.

With a coordination process, F23 can see notable improvement in WIP management and waiting issues associated with PM activities. To guide F23 in this coordination process, an operational guideline was created.

4.4 Guidelines for Coordinating Preventative Maintenance

F23 wanted a way to communicate the findings of the PM WIP models in a way that the manufacturing team could apply findings to their operation. Results of the WIP models were evaluated with a variety of members of the manufacturing team. During the discussions of different model scenarios, ideas on how to manage operations to minimize waiting time from PM were generated. These ideas were translated into operational guidelines for PM coordination which would be used to educate manufacturing technicians (MTs). The objective of the guidelines was to assist MTs in making decisions to coordinate PM activities between process steps to minimize waste from waiting WIP. The coordination process should be started when a PM is due on a tool in 1-7 days. When coordination decisions need to be made, the downstream tools should make the ultimate decision as they are the customer of the upstream tools and can indicate their WIP needs. The following guidelines are being used to train all of the MTs on how to appropriately coordinate PMs.

Good Opportunities to Start Preventative Maintenance

- Your tool has minimal/zero WIP waiting.
- The upstream process step does not have WIP to feed your tool.
- The upstream tool has a PM due, so you can both do PMs at the same time.
- The downstream tool has a PM due, so you can both do PMs at the same time.
- Your operation and upstream/downstream tools are in a low priority area as determined by the IPQ WIP management system mentioned in Chapter 3. In this case, you should also coordinate PMs in upstream and downstream segments if they are also low priority areas.
- Your tool is already down for repair, and you can include PM requirements in your activities.
- The downstream tool has enough WIP/buffer to feed them through your PM period. If the downstream tool has a large WIP bubble, this is a great opportunity for PMs.

Bad Opportunities to Start Preventative Maintenance

- Upstream tool has already started PM and will finish their PM before you can finish your PM. This will build a WIP bubble and cause WIP to wait for PMs twice.
- Your tool has been starved, but significant WIP will be arriving during your PM.
- There is WIP waiting at your tool and the downstream tool is starved or underutilized. If this is the case, you may need to process WIP for them and then start the PM.

Questions to Ask in Your Process Area

- Are there other tools in the same toolset which have PMs due?
- Are there potential time efficiencies by doing PMs at the same time? If so, does the toolset have adequate capacity to quickly recover and move WIP downstream?
- Or should you space out the PMs to continue moving WIP and feeding downstream operations in need?

Once You Have Decided to Start Preventative Maintenance

- If PMs are due in multiple areas, coordinate them so PM activities at both steps are completed by the same time. It is especially detrimental to have the downstream tool in PM once WIP starts processing out of your tool. This causes unnecessary waiting at both tools.
- Notify upstream and downstream tools of your PM, when you are starting, how long it will take. If you will go over your time estimate by one hour, notify these teams in advance. This communication will allow the areas to plan and prioritize their WIP processing, PM and training activities appropriately.

4.5 Ideal State for Preventative Maintenance Coordination

In addition to coordinating PMs with the operations guidelines, there are other improvements which can be made. Ideally, F23 should have one consolidated list of all PM due dates for all functional areas. The shift manager and operations managers should use the list on the first day of their work weeks to evaluate what PMs are due in the next few days. As a team, they should discuss factory goals, equipment issues and WIP profiles to determine how to coordinate PMs in a way that will maximize processed WIP and minimize wait times.

Currently, a staff engineer is consolidating PM due date information in a database on a tool by tool basis. The data is being communicated in pieces to different functional areas. If the existing data were communicated in one package, shift managers and operations managers could start cross-functional coordination with the data immediately. As the PM data set becomes more complete, the management team will be able to make more strategic PM decisions to benefit the entire fab's WIP management.

4.6 Conclusion

F23 has little coordination of their PM activities. A WIP model showed that there could be significant reductions in PM related wait times if PMs were coordinated among process steps. The PM Coordination Guidelines are being incorporated into required training for all manufacturing technicians to ensure that coordination concepts are understood and consistently communicated throughout the fab. Ideally, one complete list of PMs would be used by the management team to make strategic decisions about PM scheduling for all steps in the fab process. The shift managers and operations managers will need to promote and champion use of coordination techniques for the process to take hold in the fab.

Chapter 5: Evaluating Current Preventative Maintenance Activities

As previously noted, equipment downtime due to preventative maintenance (PM) and failures was a significant obstacle to balancing WIP flow and reducing cycle time at F23. Due to frequent tool failures, I decided to investigate the effectiveness of F23's PM activities.

Intel has standard PM procedures for tool sets which are used across fabs, and occasionally their frequencies are tailored to a specific fab or product. For the most part, however, the procedures are the same across fabs and have not been evaluated for time effectiveness or their effectiveness at preventing failures. Thus, the objective of the PM execution investigation was two fold:

- Evaluate the time consumed by scheduled PMs on High Precision Maintenance (HPM) tool sets.
- Identify and prioritize actions to renovate PMs and improve tool performance.

The HPM tool sets represent key families of equipment in each of the functional areas of the fab including implant, lithography, etch, and thin films. A brief overview of the HPM tools is as follows:

Tool Name	Function
Implant 1	Implants dopants (which alter conductivity) using high voltage
Lithography 1 (Litho1)	Puts etch pattern on wafer through lithography
Lithography 2 (Litho2)	Puts higher resolution etch pattern on wafer
Etch 1	Etches metal from pattern on wafer
Etch 2	Clean wafers after implant, lithography and etch steps by immersing them in chemicals
Thin Films 1	Lays a thin film of dielectric insulation between metal layers
Thin Films 2	Lays a thin film of dielectric insulation with more precise dimensions

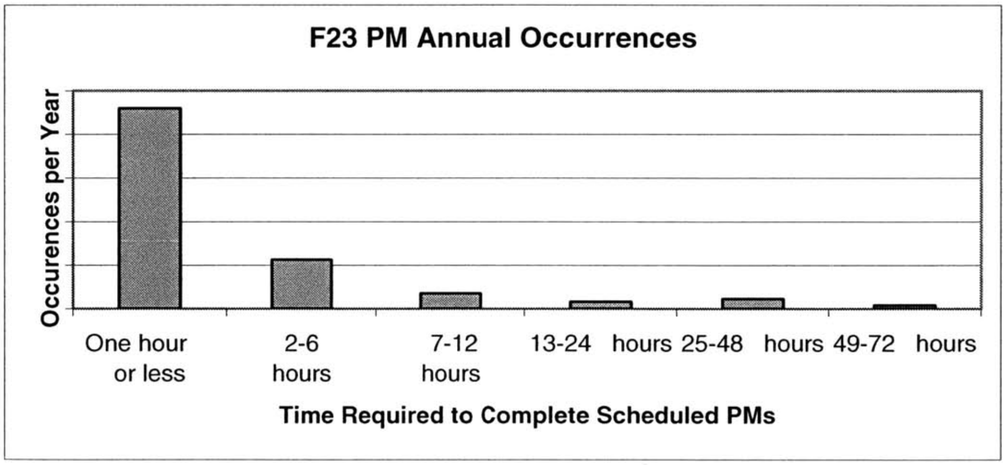
The preventative maintenance activities of these tools were evaluated for their time requirements and effectiveness at preventing failures.

5.1 Time Requirements for Scheduled Preventative Maintenance

To evaluate the current PM activities, it was necessary to gather PM requirements and time estimates for each of the HPM focus tools. Specifically, data was collected on the required PM tasks, the frequency of each PM task and the average time to complete each task. The required PM tasks and their frequencies were obtained from equipment specifications and validated by engineers. The engineers responsible for each tool set estimated the time to complete each PM as automated data collection methods were unreliable and inconsistent for this information.

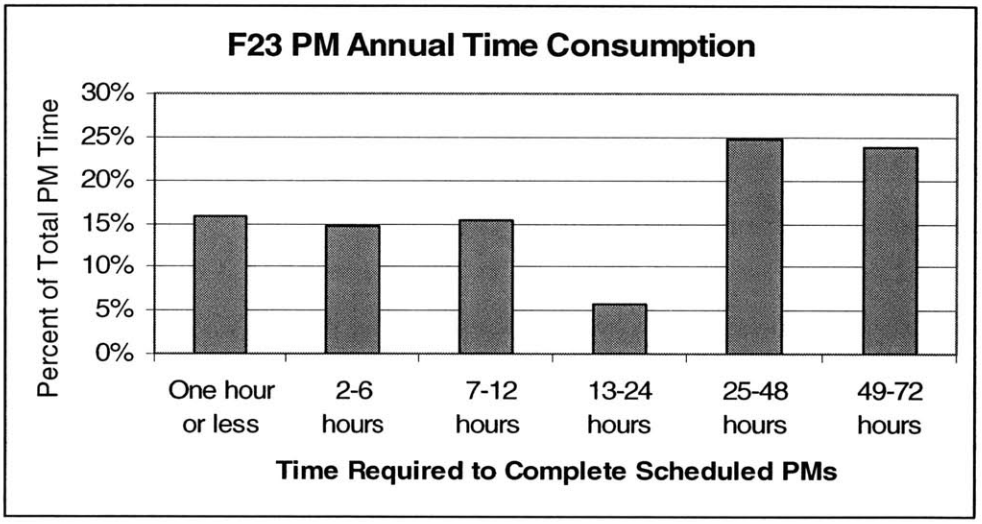
The data collection resulted in the estimation of annual PM time requirements of over 200 PM processes which represent over 6500 PM executions per year. At a glance, the vast majority of PMs, approximately 70% of them, are done very frequently and completed in one hour or less as seen in Figure 8: F23 Preventative Maintenance Annual Occurrences by Length of Activity.

Figure 8: F23 Preventative Maintenance Annual Occurrences by Length of Activity



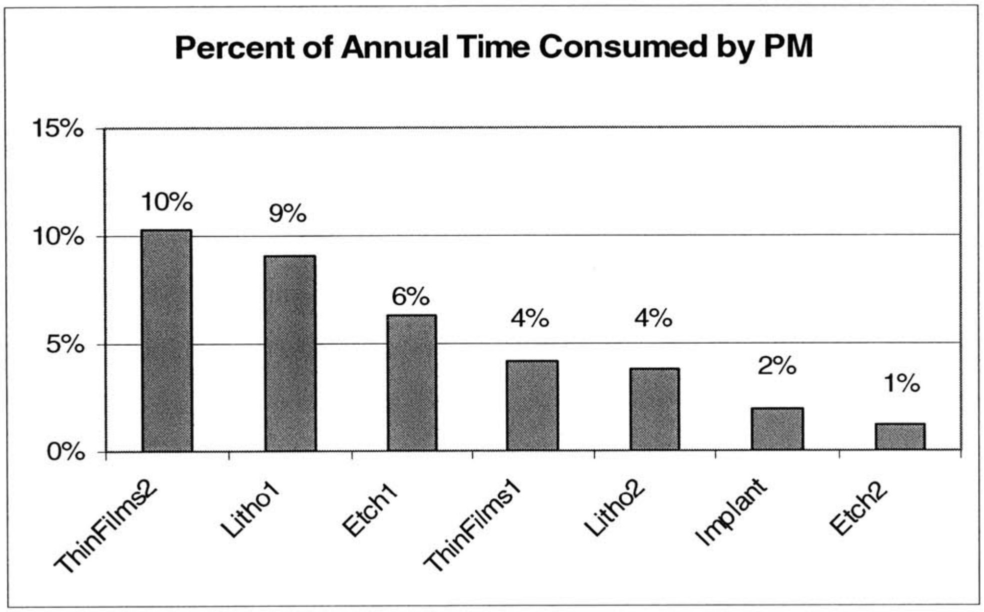
Although most of the PMs are completed in less than one hour, almost 50% of the total PM execution time lies with PMs that take greater than 24 hours as seen in Figure 9: F23 Preventative Maintenance Time Consumption by Length of Activity. These time consuming PMs typically occur quarterly and are often overlooked for improvements due to their infrequency. As each HPM tool is evaluated, these time consuming PMs should be given serious consideration for improvement resources.

Figure 9: F23 Preventative Maintenance Time Consumption by Length of Activity



To communicate tool-specific data, results were tabulated by tool families to show what percent of annual time was consumed by scheduled PMs (see Figure 10: F23 Annual Time Consumed by PM for HPM Tool Sets). The management team was surprised that on two of the tool sets, PMs consumed approximately 10% of their operations time, a quantity that seemed high. After all, using 10% of the time for PM meant that they were effectively reducing their capacity by 10% in bottleneck areas.

Figure 10: F23 Annual Time Consumed by Preventative Maintenance for HPM Tool Sets



After reviewing the total hours spent on PMs, F23 wanted to investigate ways to reduce PM time requirements in Thin Films, Lithography and Etch functional areas.

5.2 Opportunities for Off-line Repair

After evaluating the time requirements for PMs, an investigation began into how to complete the required PM activities in less time. This presented a ripe opportunity to explore opportunities for off-line repair. With off-line repair, a spare refurbished component is swapped into a tool for an old component in need of maintenance. Once the spare has been installed, the machine can be online faster than if the maintenance process had to be completed while the tool was down. Instead, once the tool is up, a manufacturing technician completes the maintenance requirements on the old part, so that it will be refurbished and ready for installation the next time the PM is required. In the past, off-line repair initiatives were not pursued because F23 was more concerned about the cost of additional parts than the impacts of downtime.

F23 has already identified two opportunities for off-line repairs on Thin Films tools. The first opportunity is on a routine valve maintenance activity. Currently, a two hour process is required to remove, clean and replace a valve. This valve preventative maintenance is completed 5-6 times per month across all tools in the family. The proposed off-line repair will reduce downtime from two hours to 15 minutes, resulting in approximately 115 more hours of uptime per year on a critical tool set.

The second off-line repair opportunity is on a substantial quarterly PM which takes 36-48 hours to complete. The off-line application will remove approximately 12 hours of downtime for each PM. As previously mentioned, infrequent PMs are often overlooked for improvement opportunities. This is an excellent example of why serious investigations should take place on sporadic, yet time consuming, PM activities. This particular tool set consists of seven individual tools, each of which encounters this PM four times per year. The end result of the 12 hour reduction is approximately 336 more hours of annual uptime for this toolset. Portions of these off-line repairs have been implemented successfully. The team is enthusiastic and waiting for additional spare parts to arrive before the full scope of the off-line activities can be piloted.

However, the engineers are skeptical about cultural issues which could impair these off-line repair opportunities. Manufacturing technicians (MTs) are expected to process WIP through the fab if they are not attending to a down tool. At the MT level, F23 is typically run very tactically with WIP processing being the most essential task. With off-line repair, WIP processing may be de-prioritized for rebuild tasks which may not immediately contribute to daily goals. The concern with this is whether or not MTs will be able to prioritize refurbishing the old part, so it is ready for the next PM. If rebuilds are not completed until the next PM, then there is no uptime gain associated with the process.

The second concern is that MTs do not trust each other to refurbish parts correctly. If someone else refurbished a part, an MT will be tempted to validate their peer's work and perhaps replicate some of the work to ensure that it was done correctly. This concern is valid especially if MTs are rushed to rebuild spares because they need to return to wafer processing.

Both cultural issues can be remedied. First, management can support off-line repair time and encourage completion of refurbishment work within a period of time after PM completion. Management buy-in and encouragement will increase after successful pilots illustrate the payoff for off-line activities. Thus, it is important that the initial off-line repair experiments be well-planned and successful in reducing PM downtime requirements. Second, the refurbishment processes need to be well documented and enforced. If engineering and management stress the importance of following the off-line processes, MTs will have confidence that refurbishment activities have been done by their peers with high quality. Additionally, engineers recommend shrink wrapping, signing and dating refurbished spares. This will ensure MT responsibility for rebuild work and validate that no one has tampered with completed work.

An initial obstacle to doing off-line repairs is having sets of replacement parts for PM activities. In the recent past, the engineers were urged to reduce the costs of spare parts which effectively reduced spares inventory and associated expenses. This severely limited opportunities for off-line repair. To justify additional spares for off-line repair in the future, it is recommended that engineers write-up why they need spares, how much time it will save and how much it will cost. Engineering managers should review and discuss the proposals and approve cost plans to support the HPM initiative. This financial support will illustrate F23's commitment to HPM activities, bolster off-line repair projects and be a morale boost for MTs and engineers.

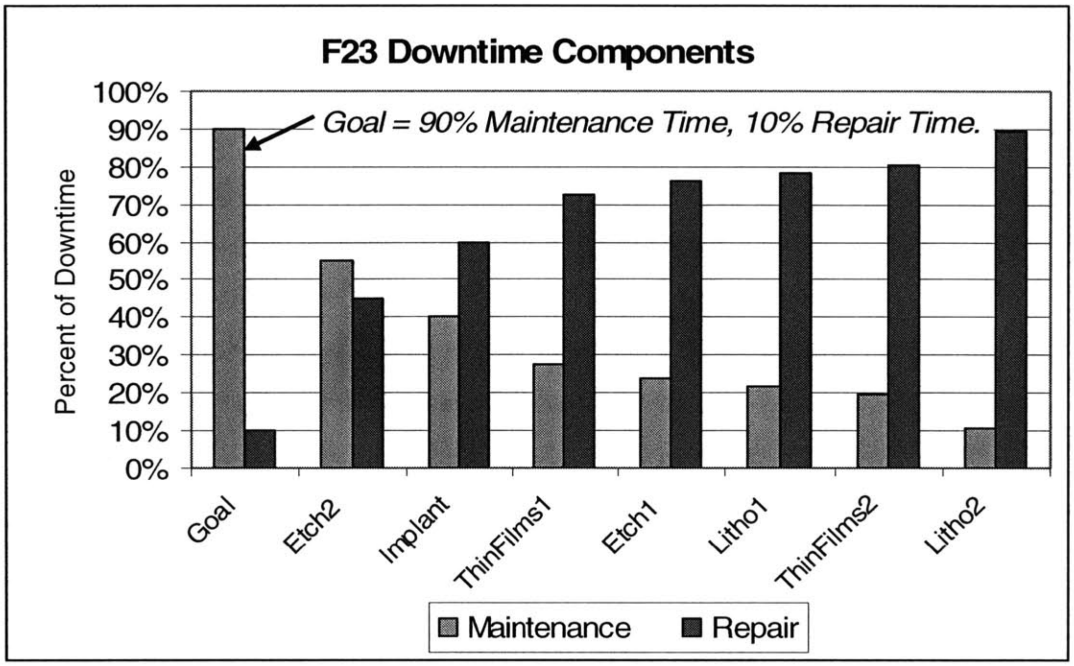
A secondary obstacle to implementing off-line repairs is the lack of a workspace for maintenance activities. Current maintenance work is done adjacent to tools being maintained. Since the tools are down, it is acceptable to potentially block access to them. However, with off-line repair, this scenario is not acceptable. The MTs will need to be creative in finding workspaces in the fab for completing the offline maintenance. Ideally, a maintenance area would be provided and include clean workspaces, ventilation, supplies and hand tools for off-line repair activities.

5.3 Preventative Maintenance Effectiveness at F23

In addition to reducing PM time consumption through off-line repair, F23 needed to evaluate the effectiveness of their PM activities. After a maintenance benchmarking visit to Agilent Technologies in Fort Collins, Colorado, F23 wanted to baseline the performance of the PM activities. To do this, the Agilent team recommended comparing maintenance downtime to repair downtime. According to industry benchmarking surveys, "effective" preventative maintenance is comprised of 80% scheduled maintenance and 20% reactive maintenance. Best practices are above 80% for scheduled maintenance with the highest benchmark at 90% (Wireman, 2004). Agilent's belief was that "best in class" maintenance organizations spent 90% of downtime on maintenance activities and 10% of downtime on repair activities. As stated earlier, the goals of F23's High Precision Maintenance (HPM) team was to become the best maintenance organization in the world by the end of 2006. Thus, they adopted the 90% maintenance, 10% repair as a performance goal.

To establish current maintenance performance, maintenance and repair data were collected for all of the HPM focus tools. For the purposes of this analysis, maintenance downtime includes preventative maintenance activities and performance monitors. Repair downtime includes all unscheduled downtime due to failures and associated fixes. Downtime data from each of the seven HPM toolsets was collected from a 12 week period in early 2005 and is displayed in Figure 11: F23 Downtime Components for HPM Tool Sets.

Figure 11: F23 Downtime Components for HPM Tool Sets



This data shows that F23 maintenance activities were not as effective at preventing failures as F23 desired with their 90% maintenance, 10% repair time goal. For example, only one of the tools spent more than 50% of their downtime doing maintenance. This established that significant maintenance work needed to be done to meet F23's "Best in Class" goal.

Upon additional investigation, it was apparent that during repairs equipment teams were not evaluating the root causes of failures and developing corrective actions to include in the PM activities. Discussions with several engineers and the engineering manager confirmed that root cause analyses were not being completed. They were focusing on bringing tools back up and not analyzing the situation. They remained in a continuous cycle of treating symptoms of the root cause, but never eliminated the root cause. These habits meant that they were not working to positively change their maintenance v. repair ratios.

It is recommended that F23 spend more time refining maintenance practices rather than improving troubleshooting skills for repairs. By focusing on maintenance, rather than repair, F23 could have a standardized process and minimize their reliance on the varying troubleshooting abilities of maintenance technicians. This will help make maintenance activities more effective at reducing unscheduled repairs, thus driving the maintenance v. repair ratios.

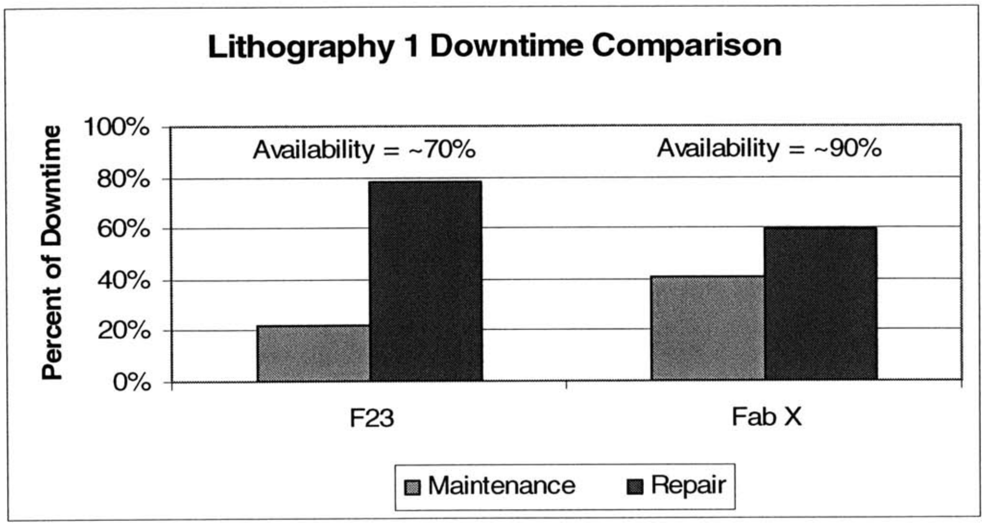
Although there are a variety of ways to evaluate maintenance performance, the maintenance v. repair method was chosen for two reasons. First, Aglient's success in driving improvement using these metrics had been very effective. Second, at F23, other maintenance metrics such as mean time to failure and mean time to repair did not have data available or reliable across tool sets. Alternatively, this maintenance v. repair downtime data was available to compare performance across tool sets.

5.4 Benchmarking Intel Preventative Maintenance Effectiveness

After understanding F23's initial maintenance effectiveness, a benchmarking of Intel's fabs was conducted to compare maintenance versus repair ratios and overall tool availability (uptime) for HPM toolsets. For each toolset, data was collected for tool availability at each of Intel's 200mm fabs over the same 12 week period. To validate stability of the data this 12 week period was compared to a different 12 week period in 2005; data was consistent across both sets indicating a viable benchmarking opportunity. To drill into the data, F23 was compared to the fab with the highest availability for each toolset. Additionally, the maintenance versus repair ratios were calculated for the fab with the best availability and compared to F23.

For the majority of the toolsets, the fab with the highest availability also spent more of their downtime performing preventative maintenance than F23. This indicated that preventative maintenance activities at other fabs were more effective at preventing failures and unscheduled repair. The following example in Figure 12: Lithography 1 Downtime Comparison illustrates this.

Figure 12: Lithography 1 Downtime Comparison



Fab X has significantly higher availability and spends twice as much of their downtime on maintenance than F23. Furthermore, this data becomes even more powerful when it is translated into a scenario for 100 hours of operation as seen in the table below.

Statistic	**F23**	**Fab X**
Total Operation Time	100 hours	100 hours
Downtime	30 hours	10 hours
Maintenance	6 hours	4 hours
Repair	24 hours	6 hours
Actual Maintenance v. Repair Ratio	1 : 4 hours	1 : 1.5 hours

Fab X actually spends less total time doing preventative maintenance which results in fewer hours of repair. As shown in the Actual Maintenance versus Repair Ratio above, Fab X's preventative maintenance is at least twice as effective as F23 at minimizing unscheduled downtime from repair. This is just one example of benchmarking which reinforces the 90% maintenance, 10% repair goal. Four other similar examples were shown to the F23 management teams which indicate that two specific Intel fabs have superior availability and maintenance effectiveness than F23.

However, the comparisons of the remaining two HPM tool sets show that preventative maintenance effectiveness is not the only control factor for availability. These examples include one tool set with identical maintenance v. repair ratio as F23, but different availability (see Figure 13: Etch 2 Downtime Comparison). The other example shows identical tool availability but different maintenance v. repair ratios (see Figure 14: Lithography 2 Downtime Comparison). This data is shown as a reality check that there are many variables which can impact tool availability, not just the maintenance versus repair ratios.

Figure 13: Etch 2 Downtime Comparison

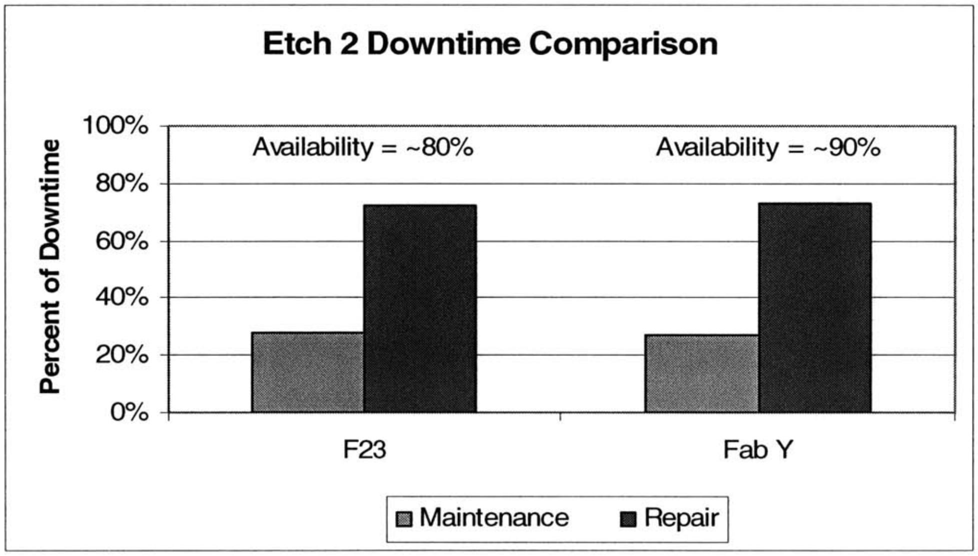
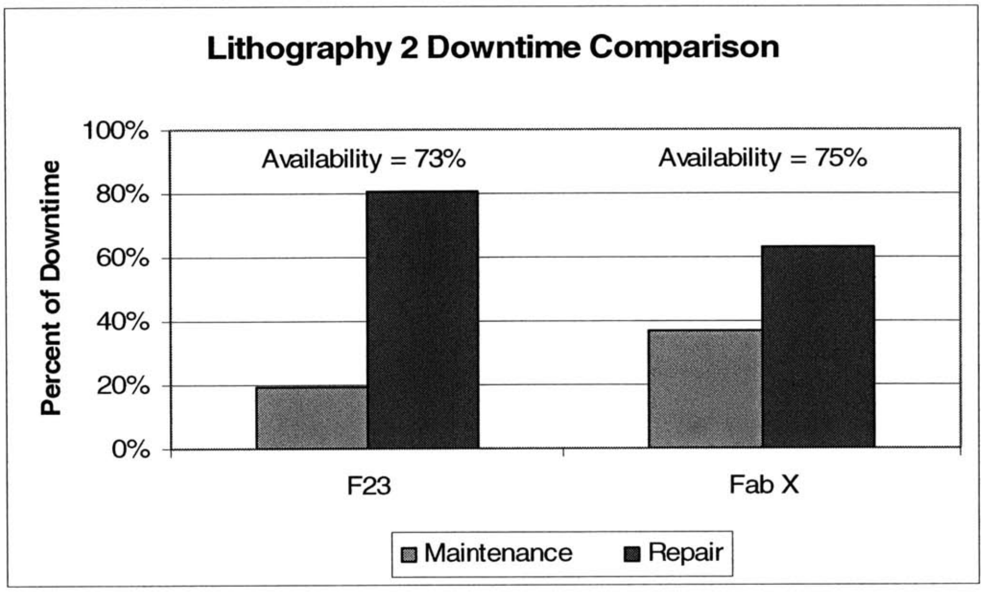


Figure 14: Lithography 2 Downtime Comparison



In the short term, it is recommended that F23 ask the two higher-performing fabs for their preventative maintenance best practices and implement applicable processes at F23. This collaboration will deliver quick results to F23, help them understand Intel's best performance and improve upon best practices. It will also eliminate unnecessary duplication of efforts which frequently occurs at Intel due to minimal sharing among fabs.

5.5 Prioritization of Preventative Maintenance Improvements

F23 should prioritize HPM efforts by analyzing the root causes of tool failures and implementing corrective actions into PMs, so the same problem does not return. This will shift the downtime maintenance v. repair ratios to increase the portion of time spent on maintenance and help stabilize overall machine performance. Once maintenance practices are revised and standardized, F23 should reduce overall PM times by implementing off-line repairs and swap procedures which will reduce the downtime for PM activities.

Once machine stabilization has occurred, sustaining activities may include revising or eliminating ineffective PM steps to further refine PM process. However, before this is started, F23 needs to get control of performance and understand if each PM step is value added. At this time, the teams do not have this level of understanding.

5.6 Conclusion

F23 has a baseline of their PM effectiveness which indicates that there are abundant opportunities for improvement. F23 needs to make PMs more effective by addressing root causes of failures; this will drive them to their downtime goal of 90% maintenance, 10% repair. For PM tasks involving component or sub-assembly maintenance, off-line repair opportunities and requests for spare parts should be approved once engineers have evaluated time savings. Addressing root causes of failures and applying off-line repairs should result in more effective use of PM downtime. Finally, infrequent, yet time consuming, PMs should not be overlooked for improvements.

Chapter 6: Observations and Recommendations

This chapter is provided to summarize observations and recommendations from the six month internship.

6.1 Preventative Maintenance

Significant WIP management issues stem from equipment downtime. F23 needs a way to minimize the impact to WIP flow and to cycle times from scheduled PM activities. There are opportunities to systematically minimize the impacts of PMs including coordinating PM scheduling and increasing maintenance effectiveness. WIP models show that coordinating PMs within a family of tools and among process steps could reduce unnecessary queue time and waste from waiting. Baseline data shows that F23 PM activities are not as effective as desired at preventing failures. By implementing corrective actions to address the root cause of failures in standard PMs, unscheduled failures will be reduced providing more operational stability. This also facilitates equipment standardization because PMs follow checklists whereas failures are addressed with non-standard trouble shooting. Intel benchmarking data indicates that other fabs have outstanding equipment availability and have decreased failures with more effective PMs.

Preventative Maintenance Scheduling Recommendations

1. Coordinate PMs using given guidelines that have been incorporated into manufacturing technicians' training.
2. Ideally, generate one list of all upcoming PMs which shift managers and operations managers would use to coordinate PMs on a weekly basis.

Preventative Maintenance Execution Recommendations

1. Gather Best Known Methods (BKMs) for PM execution from other fabs to have immediate impact on equipment downtime and maintenance versus repair times at F23.

2. Investigate the root causes of equipment failures and incorporate corrective actions into PM procedures to minimize recurring failures.
3. Implement off-line repair procedures to swap in refurbished components and minimize PM downtime. Support manufacturing technicians when they request funding for spare parts and need time to fix tool components off-line.

6.2 F23

This internship has provided a unique view of the F23 organization. As an "outsider" at Intel, the following observations and recommendations were made.

Intel Software Applications

Intel has several internal software applications which are used daily by manufacturing to monitor performance and inventory. F23 is behind on updating these applications. To standardize with other fabs, F23 should be prioritized for upgrades and supported by the Intel fab organization as was seen in a recent tactical upgrade.

Recommendation: The F23 automation team should evaluate all of F23's Intel software to determine which applications have newer versions. They should evaluate the newer versions to determine how quickly upgrades should be scheduled.

Engineering Equipment Data

Engineering has a variety of data sources for equipment availability, downtime drivers and inter-fab comparisons. Many of these sources were used to compile the PM baseline and benchmarking data in Chapter 5. However, the data is not in an easily usable format and is not regularly referenced by engineers to gauge performance.

Recommendation: The HPM team should decide what metrics they want to manage and track those in an easy to access and understand format. Several days and several applications were required to gather benchmarking data. The goals of this recommendation are to generate the reports in minutes by linking a variety of databases, increase engineering's utilization of data and help drive performance.

Equipment Stabilization and Availability

Equipment stability is arguably the greatest driver of variability at F23. Unscheduled downtime and failures need to be minimized. However, F23 is not taking time to analyze the root causes of tool failures. They are in a vicious cycle of urgently getting tools back on line, but not understanding or investigating the root cause. This causes the same problems to return on multiple tools and is simply treating a symptom of the true issue. As seen in Chapter 5.4 Benchmarking Intel Preventative Maintenance Activities, tool availability increases as unscheduled downtime decreases. Therefore, eliminating recurring failures will improve availability and stabilize the operation.

Recommendation: The HPM team's highest priority should be having equipment teams complete root cause failure analyses and implement PM corrective actions.

Metrics

At times, F23 has struggled with metrics identification and management. To use metrics effectively, they should pick meaningful metrics, set goals, communicate the goals and track to the goals. For manufacturing specific metrics, engaging manufacturing technicians in goal setting and tracking will help drive performance. If performance issues do arise and people get fired up, then F23 has effectively caught their attention and started to drive behavior.

Recommendation: F23 can practice this by clearly communicating cycle time and High Precision Maintenance goals throughout the fab organization. Both initiatives have apparent ambiguity which could be remedied by clearer metrics and communication. To cement the metrics, they could be included in annual performance plans with specific goals for which engineers and manufacturing technicians would be held accountable.

Corporate "Push" Culture

Intel's corporate culture is on based on the "push" methodology of monitoring performance based on what work has been started in the factory; this has led to excess inventory at F23. Furthermore, this mentality is contrary to their lean manufacturing efforts which advocate a "pull" methodology. Pull methodologies monitor performance and dictate production goals by looking at customer demand.

> "The 'magic' of pull systems is that they establish a WIP cap, which prevents producing unnecessary WIP that does not significantly improve throughput. The result is that pull systems reduce average WIP and cycle times, reduce variability of cycle times, create pressure for quality improvements and (by decreasing WIP) promote more effective defect detection, and increase flexibility for accommodating change" (Hopp).

In fact, F23 has been reprimanded by the Fabrication Sort Management (FSM) organization for pull activities which were used to reduce inventory and cycle time. If Intel is truly committed to lean manufacturing, they will need to adjust the mindsets of executives who have been practicing "push" for many years.

Recommendation: The F23 plant manager and corporate cycle time team need to educate executives on why pull is a more effective way to manage and measure the fab network. A pull class, simulation or activity may illustrate this effectively. Additionally, the corporate cycle time team should promote pull activities by developing corporate metrics with pull foundations. Success stories should be shared with executives and the fab network to promote the cultural change.

Excess Inventory

F23 has had issues with excess inventory which generates unnecessary waste in the fab. Using Little's Law:

Inventory (wafers) = Cycle Time (weeks) * Wafer Outs (wafers/week),

F23 can determine their desired inventory level based on their goals for cycle time and wafer outs per week. If their actual inventory is greater than the Little's Law inventory, they have too much inventory which will impair performance for cycle time, wafer outs or both.

Recommendation: F23 should evaluate cycle time goals and customer demand to establish a maximum WIP level for the fab. This goal should be well documented and communicated to executives because the fab may need to reduce starts contrary to the corporate "push" methodology. Then, pull activities will be viewed more as a proactive strategy to WIP management rather than a reaction to tactical issues.

Sharing Among Intel Fabs

F23 is the only Intel fab making one specific flash product. This affords them luxury of autonomy in process decision making. In other circumstances when two fabs make the same product, the fabs are required to coordinate process changes to adhere to the corporate Copy Exactly policy. In F23's situation there is relief that they are not bogged down by working with other facilities, but they do not reap the benefits of sharing and benchmarking with other operations.

The previously mentioned software issue is a great illustration of how Intel is not sharing. Intel's fabs have tremendous intellectual horsepower which F23 can leverage and share to make the entire fab system more productive. If relationships among fabs were more open and supportive, fabs would communicate successes, failures and current challenges and learn from each other. Currently there are great opportunities for these types of activities, but the fab organizations need to be reminded that it is ok to ask for and offer help.

Recommendation: Intel can utilize the network of MIT Leaders for Manufacturing interns to facilitate sharing among fabs. F23 can increase cross site communication by scheduling regular meetings with other groups of fab to ensure that F23's sole sourced status does not impair sharing. Additionally, F23 can schedule benchmarking visits to other fabs to learn from their experience and enhance organizational relationships.

F23 Recommendations for Future Leaders for Manufacturing Interns

As Intel and F23 continue their relationship with the MIT Leaders for Manufacturing (LFM) program, they may have additional interns. In the near future, the following three topics would be appropriate for LFM intern projects:

- Stabilizing equipment performance and maximizing availability on a key toolset.
- Developing WIP management strategies for multi-process fab and determining how to manage multiple priorities.
- Developing a tool to coordinate WIP management and PM scheduling activities.

6.3 Conclusion

Intel's F23 in Colorado Springs is enthusiastic about additional process technologies and long term viability from the corporate long range plan. By implementing preventative maintenance recommendations and maintaining focus on WIP management and equipment uptime, they can meet or exceed Intel's corporate cycle time goals.

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