Development, Implementation, and Application of Project Prioritization System in Wafer Fabrication Manufacturing

by

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Submitted to the Department of Civil and Environmental Engineering
and to Sloan School of Management in partial fulfillment for the degrees of
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Abstract

With each generation of microprocessors, Intel wafer fabrication manufacturing is driven by the market to produce higher volumes of microprocessors in less time. Meanwhile, the cost of building and maintaining a wafer fabrication facility has been increasing significantly year after year. The combination of high production volume pressures and increasing manufacturing costs makes an effective project prioritization system critical for wafer fabrication manufacturing.

Intel Corporation, the world's leading manufacturer of microprocessors, has made manufacturing one of its core competitive advantages. Maintaining manufacturing as a core competitive advantage is very expensive. A new wafer manufacturing facility costs around $1.5 billion to $2.0 billion. It is imperative for Intel that the invested capital is fully utilized for maximum profitability. An effective project prioritization system for wafer fabrication manufacturing can be part of an overall strategy to help maximize profit.

The purpose of this thesis is to present a project prioritization system for the wafer fabrication manufacturing environment that can help effectively utilize its limited resources. This thesis reports on a recommended project prioritization system and its initial use. The following key issues are addressed:

- Why is a project prioritization system at Intel wafer fabrication important?
- What is the current project prioritization system?
- Why is the current project prioritization system inadequate?
- What is the recommended project prioritization system?

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1. Introduction

Project prioritization is ranking of projects on the basis of expected return from completing a project. The return is typically measured by output versus input. Output is the benefit gained from completing a project and input is the required resources in order to complete the project. Organizations and individuals prioritize projects, because, in nearly all cases, the work is plentiful and resources are limited. Prioritizing helps to focus the resources on the efforts that will yield the greatest return.

This thesis project attempts to develop a working project prioritization system for wafer fabrication manufacturing at Intel. Specifically, the system will help prioritize engineering projects that are geared toward sustaining manufacturing operations or increasing production volume. The challenge for wafer manufacturing is to identify the areas of improvements that will render the highest possible increase in output, while maintaining safety and environmental standards.

1.1 Project Prioritization

There are numerous methods of project prioritization. These methods range in complexity and subjectivity because each method attempts to balance the reality of practical application versus pursuit of accuracy. The method that is ultimately used by an organization is chosen based on need and capability. Need is driven by the type of decision an organization needs to make. Capability is driven by tools, skills of people, structure of organization, and support of management.

A project prioritization method is merely a tool to assist in decision making: decision makers, rather than methods, bear the responsibilities for decisions. The project prioritization method's role is to reduce qualitative and quantitative data into information that will shed some light on a current issue or decision. While no method can completely eliminate risk associated with decision making, a good method will reduce such risk.

In the case of wafer manufacturing at Intel, a prioritization tool would be useful for directing engineering efforts. Implementation of highly specialized methodologies for prioritizing individual projects is not practical. It is too difficult to quantifiably predict an outcome of a given project. For example, the system should help direct whether more engineering efforts should be placed in improving line yield versus die yield. Basically, the system will help choose one or the other based on comparison of the potential gain in production output from improving line yield or die yield.

The expected result of the prioritization methodology is to determine ways to more effectively utilize the available resources. The proposal will touch upon the broad scope of project prioritization, yet, it will contain specific and practical contents that can be implemented at the manufacturing and engineering level.

1.2 Project Prioritization System Needs at Intel

A formal project prioritization system has not been established in the latest virtual factory. The "virtual factory" is a group of wafer fabrication facilities that share a common process technology. Due to a policy called "Copy Exactly," the fabs in the virtual factory network share nearly all aspects of manufacturing microprocessors. A prioritization system, once established, will be shared by all fabs in the virtual factory.

Past methodologies do not provide a complete solution in effectively allocating resources. The past methods satisfied limited aspects of overall prioritization. The need for a new project prioritization system exists for the following reasons: lack of clear picture on the overall improvement opportunities for the entire virtual factory; unclear tracking of projects; and weak system for communicating information.

What drives the need for an effective project prioritization system at Intel wafer fabrication manufacturing is simple: a sheer pressure to better utilize the resources. The cost of manufacturing microprocessors is climbing astronomically. The production volume ramp-up rate is higher with each generation of microprocessors. A project prioritization system is part of an overall solution for Intel wafer fabrication manufacturing to increase productivity.

In the beginning of the decade, the cost to build a wafer fabrication facility reached about $1.0 billion. Now, it costs around $1.5 to $2.0 billion, and is expected to reach as much as $10 billion at the beginning of the 21st Century. A typical fab is expected to return its investment in three to five years.

While the overall cost of wafer fabrication manufacturing is increasing, demand for higher production volume is increasing significantly as well. In the past decade, demand for personal computers has grown considerably. The demand for microprocessors that power these personal computers has allowed Intel to grow and prosper. Intel chose manufacturing to be its competitive advantage to contend with the rising number of competitors that produce either Intel architecture clones or competing microprocessors. The combination of the market demand and Intel's drive for high volume manufacturing challenges the manufacturing organization to produce at higher volumes with every new generation of microprocessor. This places pressure on Intel wafer fabrication manufacturing to continuously increase productivity. An effective project prioritization system can increase productivity by appropriately allocating resources.

1.3 Thesis Structure

This thesis is divided into five main parts: Background, Project Prioritization Study, Standardized Measurement, System Description, Prioritization System in Use, and Conclusion. Section 2 (Background) explains wafer fabrication manufacturing and the importance of project prioritization in Intel wafer fabrication manufacturing and describes the current prioritization system, evaluation of the current system, and requirements for a new system. Section 3 (Project Prioritization Study) describes the background research the current prioritization system, evaluation of the current system, and requirements for a new system. Section 3 (Project Prioritization Study) describes the background research work of numerous project prioritization methods. Section 4 (Standardized Measurement) explains how the measurements were chosen for the new prioritization system. Section 5 (System Description) describes the new project prioritization system. Section 6 (Prioritization System in Use) illustrates the process taken to implement the system. It includes hypothetical scenarios of the prioritization system in action. Section 7 (Conclusion) covers the summary of the project and the key lessons learned. It includes recommendation for future research work in the related area for improvement purposes.

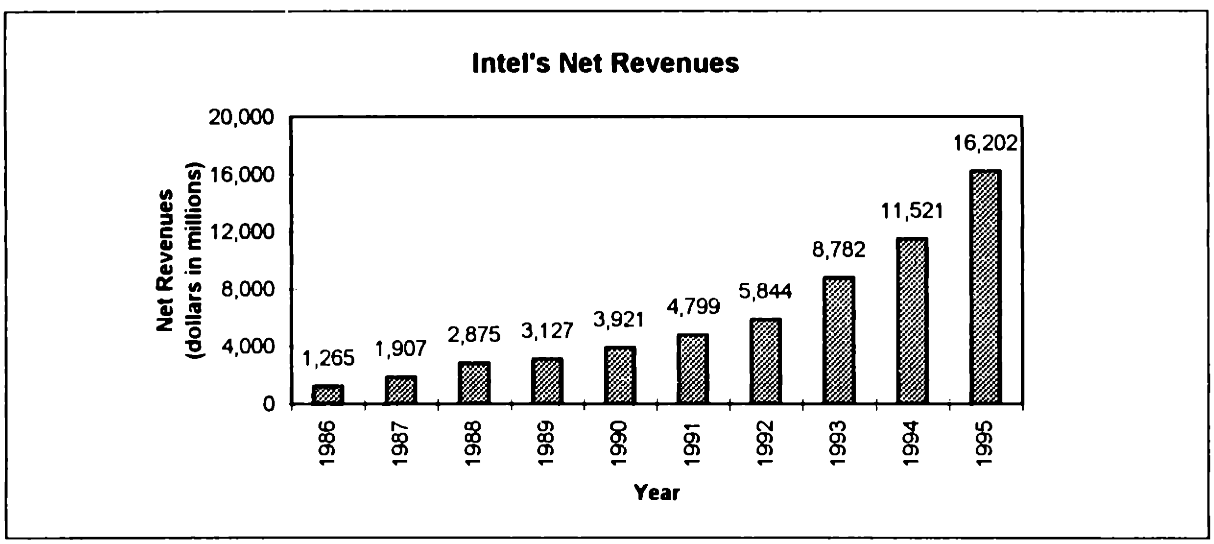
2. Background

Before discussing in detail the new project prioritization system, it is helpful to explain some background information about Intel and its wafer fabrication manufacturing. This section introduces Intel Corporation and wafer fabrication manufacturing at Intel. It then explains typical engineering projects in detail to help illustrate the type of projects that are in need of prioritization. In addition, the current prioritization system is explained.

2.1 About Intel

Intel Corporation is the largest producer of microprocessors in the world. Intel is best known for the Pentium™ and Intel486™ Microprocessors. There are over 40,000 employees working for Intel with major sites in 7 countries. In the U.S., Intel has sites in Oregon, California, Arizona and New Mexico. Currently, there are 15 wafer fabrication facilities, with some under construction, producing flash memories, microcontrollers and microprocessors. The popularity of many of these products, especially the microprocessors, has helped Intel grow significantly in the past several years. Please see figure 2.1 for Intel's net revenue in the past 10 years.

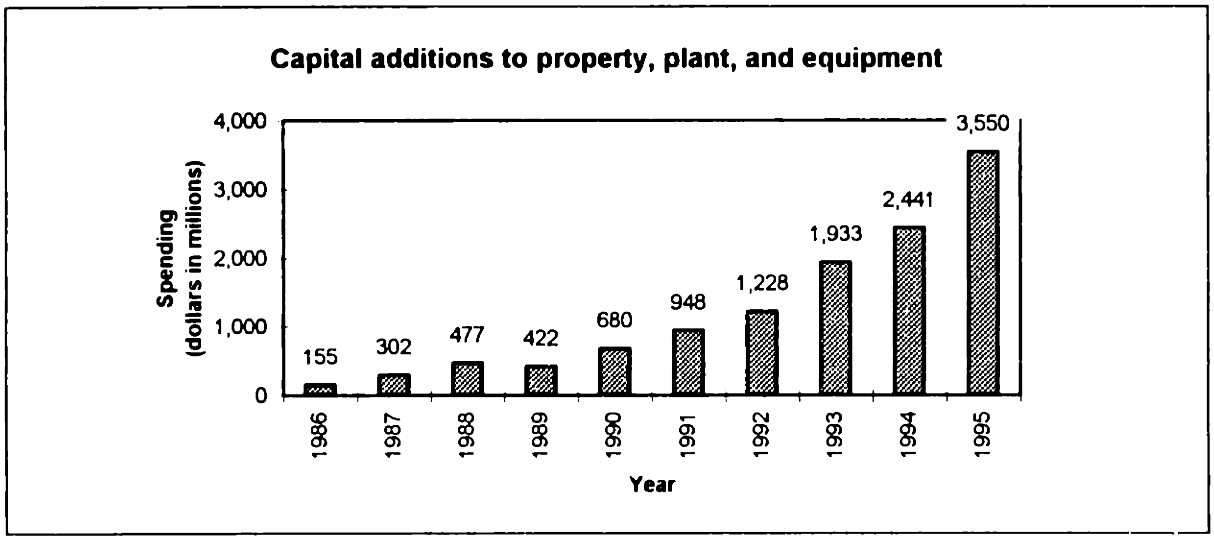
Figure 2.1 Intel's Net Revenue in the Past 10 Years



Wafer fabrication facilities, often referred to as fabs, that produce microprocessors face immense pressure to maximize their output capability. The penalty for not producing enough units is tremendous in the microprocessor business. The high demand for microprocessors has been driven by increase in the popularity of personal computers. Also, the volume of the latest proliferation or new generation of microprocessors must be increased quickly to speed up the obsolescence of the older products.

Intel, as a company, has been investing heavily in capital and equipment to increase its production volume. In the past five years, Intel has spent a little over 20% of its revenue each year on capital investment, which a large portion is for building wafer fabrication facilities. In recent years, an average of one new fab has been built or is being planned to be built every year and a half. Please see figure 2.2 for Intel's capital investment spending in the past 10 years.

Figure 2.2 Capital Investment by Intel in the Past 10 Years



In addition to significant increases in capital spending over the years, the number of employees has grown significantly in recent years to accommodate for rapid increase in production volume. Between 1994 and 1995, the number of employees has grown from

32,600 to 41,600, an increase of 27.6%. Of the 9,000 hired this past year, nearly two thirds were hired to staff manufacturing.

Fabs are built to meet the demands for the latest microprocessors. A basic manufacturing strategy is to have the latest process technology in the latest fab. It is the combination of chip design and process technology that determines the performance of microprocessors. For the first few years of fab life, the installed process technology will allow a fab to run the newest version of microprocessors. Since the margins on these chips are high, the primary focus is output volume. Even a small increase in die per wafer or wafers per day can translate to many millions of dollars, so most costs can be justified by the potential return.

Fabs may upgrade their process technology to produce the highest margin microprocessor as long as possible. However, the process technology upgrading capability is limited by the heavily invested equipment and facility set-up. Purchasing new machines or modifying facilities is not cost effective. In a matter of years, fab once producing high margin product become commodity product factories.

Once the shift from high margin to commodity microprocessor manufacturing takes place, the primary focus becomes cost. Being cost effective is key to the profitability and longevity of the fab. Fabs face great challenges in reducing costs because changing focus from high volume to cost consciousness is not easy. All the equipment investments made during the output focus stage are carried over to the new cost focus stage. and depreciation expenses can continue to remain high making it difficult to cut costs significantly.

The combination of high volume demands, quickly dropping microprocessor prices and fast changing technologies provides great challenges to semiconductor manufacturing. Coupled with these challenges is the ever increasing cost of building and maintaining wafer processing fabs.

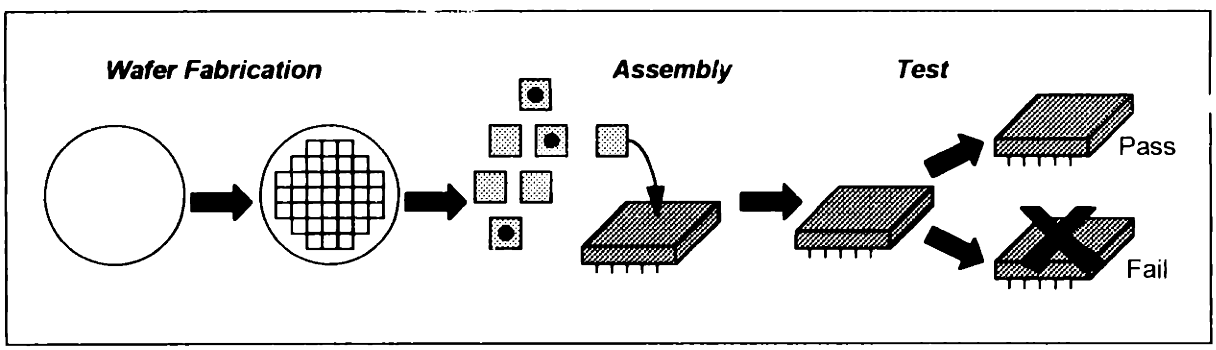
2.2 Wafer Fabrication Manufacturing at Intel

This section provides background information related to wafer fabrication manufacturing that is pertinent to understanding project prioritization. It covers process technology, different manufacturing phases, organization, and projects related to wafer fabrication manufacturing.

2.2.1 Wafer Fabrication

Manufacturing of microprocessors has three main steps: wafer fabrication, assembly, and test. Figure 2.3 is an illustration of these three steps. In wafer processing, bare silicon wafers are sequenced through numerous steps to produce functioning integrated circuits or chips. Toward the end of wafer processing, each wafer goes through testing called sort where dysfunctional chips are marked in order to easily separate them from the functional chips. During the assembly step, each chip, often called die, is separated from the other chips on the wafer. Only the unmarked die get installed inside a package. Finally, at the final test step, every packaged chip goes through functionality and performance tests to determine whether it can be shipped or not.

Figure 2.3 Microprocessor Manufacturing Steps



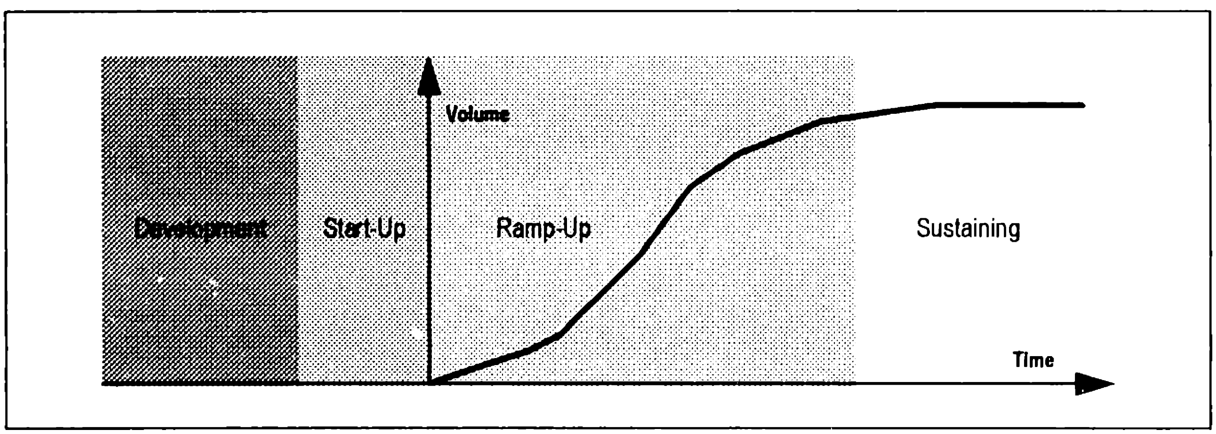
The wafer fabrication process consists of a series of lithography, etching, implantation, and deposition steps. These steps allow building of transistors, metal lines and insulation layers that make up a chip. A typical process can have over a hundred of these steps. Wafer fabrication needs to take place in a near particle free environment. Particles can interfere with the performance and functionality of chips. Some of the latest wafer manufacturing facilities operate at less than one particle of greater width than one micron per cubic foot of space.

A fully functional wafer fabrication facility costs around $1.5 billion to build. A large portion of the cost is the wafer fabrication equipment. Overall, the wafer fabrication is by far the most complicated and expensive step.

2.2.2 Wafer Fabrication Production Stages

There are four main production stages in wafer fabrication manufacturing: development, start-up, ramp-up, and sustaining. The *development stage* is when a development fab creates a process technology. The *start-up stage* consists of the process technology transfer, equipment delivery and qualification, and process certification. The main emphasis during this stage is getting the equipment up and running. The *ramp-up* stage is when a fab increases its output at a relatively high rate. The *sustaining stage* is when the factory is operating at full capacity. Volume versus different wafer fabrication manufacturing stages are shown in figure 2.4.

Figure 2.4 Different Stages of Wafer Fabrication Manufacturing



During the development stage, the development fab creates a process technology and transfers it to manufacturing fabs. The development fab is responsible for determining the type, performance, and set-up of all the equipment, in addition to determining the necessary materials and supplies that will be part of the process technology. As part of Copy Exactly, the exact process will be transferred to a manufacturing fab. The process will then go through minor adjustments as agreed by all fabs in the virtual factory.

At the start-up stage, all the pieces of equipment to begin the initial production are installed and qualified. Being qualified means that the set of equipment meets all the specifications. Along with the equipment qualification, the process is certified. Process certification is an approval procedure based on reliability robustness. It is only at this point that the chips produced can be sold, so meeting the qualification and certification deadlines are extremely crucial.

The ramp-up stage begins immediately after the process certification. During this stage the output volume increases rapidly. The volume increase is achieved by installing more pieces of equipment and by improving the performance of the existing equipment. Meeting all the equipment performance goals is critical in order to meet the scheduled output volume.

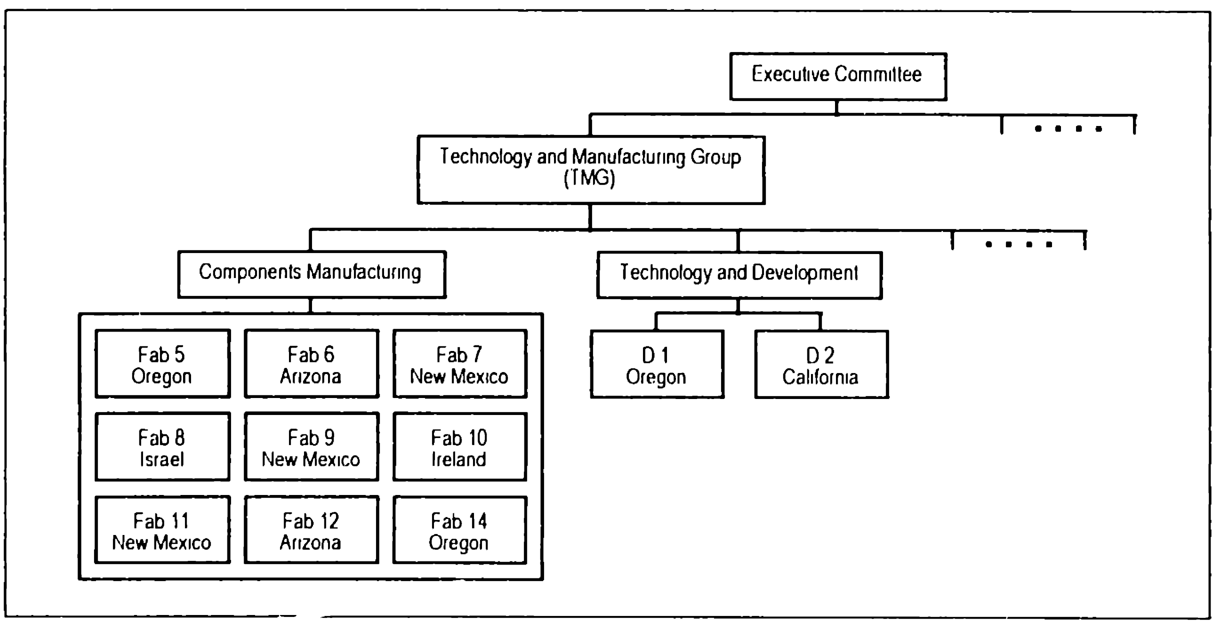
The sustaining stage is when the rate of volume increase becomes very low and output volume stabilizes. It is at this point that process engineering activity slows down and the manufacturing group takes on more responsibility. Cost reduction becomes important at this stage, so continuous improvement in productivity and cost savings are the focus. Typically, it is during the sustaining stage that the products that were being produced by the fab become commodities.

2.2.3 Organization

At Intel, wafer fabrication manufacturing is performed by two groups: Technology and Development (TD) and Components Manufacturing (CM). TD's chief role is to develop process technologies and transfer them to the fabs in Components Manufacturing where a high volume manufacturing is done. Both of these groups belong to the Technology and Manufacturing Group (TMG). TMG is responsible for all of Intel's manufacturing and manufacturing technology development. Roughly half of all Intel employees work in TMG. TMG directly reports to the Executive Staff, the governing body of Intel. Figure 2.5 is an organizational chart showing TD and CM.

CM has several corporate or central organizations it interfaces with that influence their priorities. Corporate planning helps set fab volume targets with respect to the corporate annual volume goals. Process equipment groups assist in purchasing and installing equipment and place pressures on fabs to fully utilize them. Corporate finance and human resources place certain limitations on spending and headcount.

Figure 2.5 Intel Manufacturing Organization



Fabrication facilities consist of many functional departments, such as Manufacturing, Industrial Engineering, Process Engineering, Finance, Yield Engineering, Planning and others. The department that plays the most central role in providing engineering resources to bringing up the manufacturing capability is Process Engineering. The process engineers execute nearly all projects dealing with installing and improving performance of the wafer process equipment. The demand on process engineering resources is heavy at all stages of manufacturing. During the start-up and ramp-up stages, the number of projects peak to bring up high volume production capability. During the sustaining stage, process engineering resources are reduced considerably to lower the overall manufacturing cost.

Most of the functional departments team up with the other fabs in a virtual factory to implement the Copy Exactly policies. The virtual factory is a group of fabs, both development and manufacturing, that share the same wafer fabrication process technology. The virtual factory consists of numerous teams, both management and engineering levels, that are represented by all fabs in the network. Each team is formed by equipment type or by function.

"Copy Exactly" is copying, by the manufacturing fabs, the process which has been developed by the development fabs as exactly as possible. The concept of Copy Exactly began nearly a decade ago to reduce the time required to ramp-up production volume. Over the years, Copy Exactly has evolved into a key way of doing business for Intel wafer fabrication manufacturing.

Previous to Copy Exactly, any time a process technology was transferred from a development fab to a manufacturing fab, the manufacturing fab experienced a much lower yield than that of the development fab. Bringing the yield level to that of the development fab consumed valuable engineering resources and time. By copying the process exactly, equivalent yield levels could be achieved because no modification was being done to the process during transfer and no new learning curve is required. This implies copying all features impacting the process exactly except for those that are clearly not feasible.

With the Copy Exactly policy, any change to the process proposed by anyone must be approved and implemented by all fabs in the virtual factory. Copy Exactly requires a precise cross fab communication. Multiple sets of cross-fab teams within a virtual factory communicate and approve any change to the process that will take place.

Most of the engineering activities are centered around the process engineering teams called the Joint Engineering Teams (JETs). The members of the JETs bring the pieces of equipment to their full capability and train the manufacturing technicians to fully sustain manufacturing. JETs are also responsible for improving the process once it is running. Since the Joint Engineering Management (JEM) is the management body for the JETs, it sets priorities for the JETs to follow when identifying and implementing projects.

2.3 Engineering Projects

A countless number of engineering projects are initiated and executed. During the most busy times for process engineering, which are start-up and ramp-up stages, up to 200 projects are being worked on. Projects become official when the engineering team members from the virtual factory agree to take them on and the engineering managers approve them.

Projects are initiated in several different ways. Certain projects are mandatory according to the stage of manufacturing. For example, setting up pieces of equipment must take place during the start-up stage. Support groups, such as Yield Engineering, Industrial Engineering, Environmental Engineering, and others, sometimes initiate projects to drive for improvements. For example, if yield indicators show below the acceptable levels then Yield Engineering performs analysis to identify the yield problem and works with process engineering to make improvements.

Major categories of engineering projects are safety, ergonomics, environmental, die yield, line yield, output capability, test wafers, labor productivity, automation, quality and reliability, and cost reduction. Nearly all engineering projects that are generated belong to one of these categories.

Safety, ergonomics and environmental projects always receive the highest priority. Safety projects encompass all projects geared to eliminate safety hazards for both employees and the surrounding community. Projects can range from installing apparatus to eliminate potential chemical leakage to modifying mechanical set-up to eliminate potential physical injuries to the operators. Ergonomics projects deal with eliminating health concerns. An example of an ergonomics concern could be a piece of equipment which force operators to make certain consistent motions that lead to carpal tunnel syndrome. Environmental projects are geared to meet all federal and state environmental standards. These projects attempt to reduce pollutant emissions and natural resource consumption. An example of an environmental project is to reduce water usage by wafer fabrication facilities because a typical large fab can consume millions gallons of water per day.

Die yield, line yield and output capability projects receive immense attention because these projects can directly improve production volume. Die yield projects attempt to improve the number of passing die per wafer by adjusting process parameters or reducing particles. Inapt process parameters and particles generated during the process of making these chips can often interfere with the functionality of chips. Line yield projects strive to eliminate causes that waste wafers during production. Wafers are typically lost from mis-handling or mis-processing of wafers. Projects can range from fixing automation equipment to modifying operations rules. Output capability projects are to improve the throughput capability of the stations. Throughput can be increased by increasing availability or run rate of equipment. Another solution, albeit an expensive one, is to purchase more equipment.

Test wafers, labor productivity, and automation projects are long-term improvement oriented projects. Test wafer projects are in place to reduce the number of test wafers needed so more of the wafer fabrication resources can be dedicated to production. Test wafers are used to monitor the process. These wafers go through portions or entire production steps. When a process is first set-up in a fab, test wafers make up a large fraction of the wafers that go through the factory. Labor productivity projects attempt to improve the productivity of the manufacturing technicians. Projects can range from training and setting clear operations rules to improving the people-machine interface. Automation projects are geared to improving the monitoring and operations of production.

Quality and reliability, and cost reduction projects are initiated on an as-needed basis. Cost projects are projects that are geared to reduce cost. An example project is increasing the life of certain components to reduce the cost of replacing them. Quality and reliability projects increase robustness of the process. An example would be an effort to increase the life of metal lines.

It is an objective of process engineering to be as efficient as possible with the number of projects. More projects could possibly mean more improvements; however, generating and executing too many projects can be too costly.

2.4 Current Prioritization System

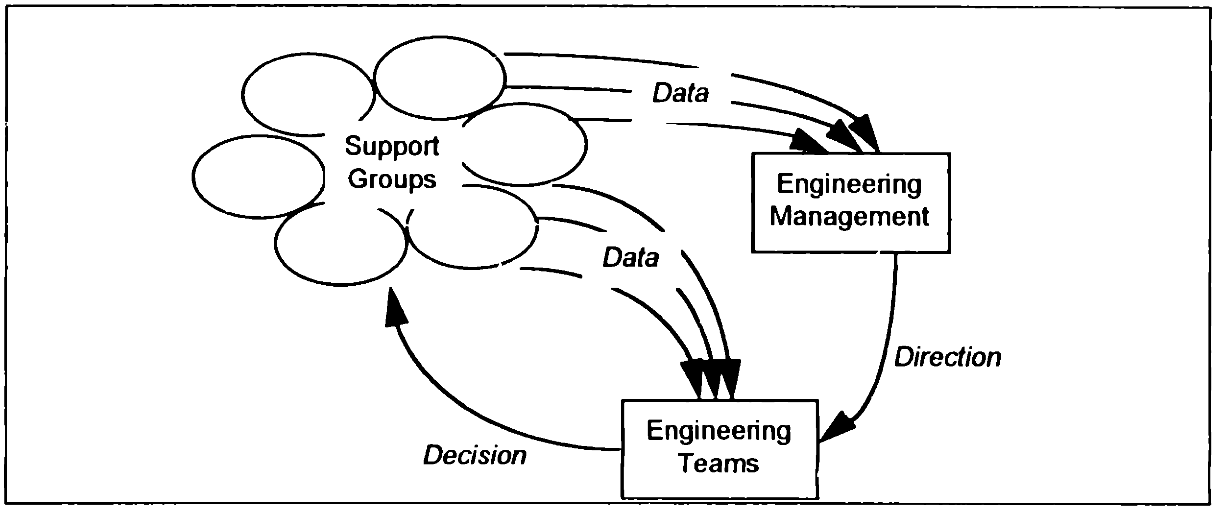
This section describes the current project prioritization system at Intel's latest virtual factory. Priorities for Intel wafer fabrication manufacturing are relatively explicitly. These priorities are based on the objectives set by the executive management. Eventually, engineering priorities are created by engineering management for the engineering teams based on the wafer fab manufacturing priorities. Many priorities are implicit because there are certain expectations depending on the phase of manufacturing also. Please see table 2.1 for an example of priorities.

Table 2.1 Trickling Down of Priorities

Hierarchy	Objectives	Role	Time Frame
Intel Mission	Do a great job for our customers, employees and stockholders by being the preeminent building block supplier to the computing industry worldwide.	Survive as an organization by providing acceptable return to investors.	Very Long Time
Executive Staff	1. Strengthen the #1 position of Intel microprocessors in the PC market. 2. Make the PC "IT" and position Intel as the leading PC communications company. 3. Back to Intel basics.	Set corporate objectives and align resources to bring highest level of profitability to the company.	Annual
Fab Management	1. Output. 2. High Yield. 3. Equipment utilization. 4. Labor productivity. 5. Cost reduction.	Manufacture products in high volume predictably at acceptable cost.	Quarterly
Engineering Management	1. Safety. 2. Rapid and controlled output ramp. 3. Output capability plan. 4. Future project list.	Align functions and individuals to meet factory objectives.	Quarterly
Engineers/ Technicians	1. Safe delivery system. 2. Qualify scan recipes. 3. Increase beam current. 4. Improve handler reliability.	Complete tasks within the function.	> Quarter

Priorities by themselves, however, are insufficient for the engineering teams to know exactly in which areas to make improvements. Over the years, wafer fab manufacturing has become more and more complex as process technology became more intricate and the demand for high volume manufacturing increased. Today, it has become far too difficult for engineering teams to identify improvement areas for their stations. Support groups have been formed to work with engineering teams to help identify and resolve issues quickly. These support groups specialize in specific aspects of wafer fabrication manufacturing. Figure 2.6 shows a process flow of the current prioritization system.

Figure 2.6 Current Project Prioritization System Process Flow



The engineering management and teams are in constant communication with the support groups to know precisely which areas of improvements to pursue. It is the responsibility of the support groups to monitor and communicate the priorities of their areas of improvement. The support groups track and decipher information for each station in the process. They provide the necessary information to help the engineering teams bring the projects to a successful completion.

To improve the allocation of engineering resources, there have been previous attempts to develop a prioritization system. The most successful two methodologies were developed in the past several years. These methods strive to quantify die yield, line yield, and output capability improvement opportunities for all the equipment stations. One method, called Equivalent Die Out (EDO) calculates the number of potential functional die improvement for each station. Higher EDO numbers means that higher level of opportunities for improvement exists.

The other method, called "Equivalent Die Out" Improvement Ratio (EIR), calculates the ratio of functional die improvement for each station. Because EIR is an improvement goal divided by current performance, a ratio greater than one shows potential improvement and a ratio less than one shows that the performance is ahead of its goals. The EIR equation is shown below:

EIR = (C + I) ÷ C

C = current capacity

I = potential increase in capacity from improvements to a station

The objective of both EDO and EIR is to provide a general measurement of potential improvement. They provide a meaningful look at the relative improvement possible for each station. Both EDO and EIR can be calculated for die yield, line yield, or output capability separately, or all these metrics can be taken together to gain an overall improvement picture.

EDO and EIR pareto graph examples are shown in figures 2.7 and 2.8. Engineering management and teams would review these graphs to identify the stations in which the most amount of improvement is possible. These pareto graphs indicate Station E as having the highest level of opportunity for improvement.

Figure 2.7 EDO Graph Example

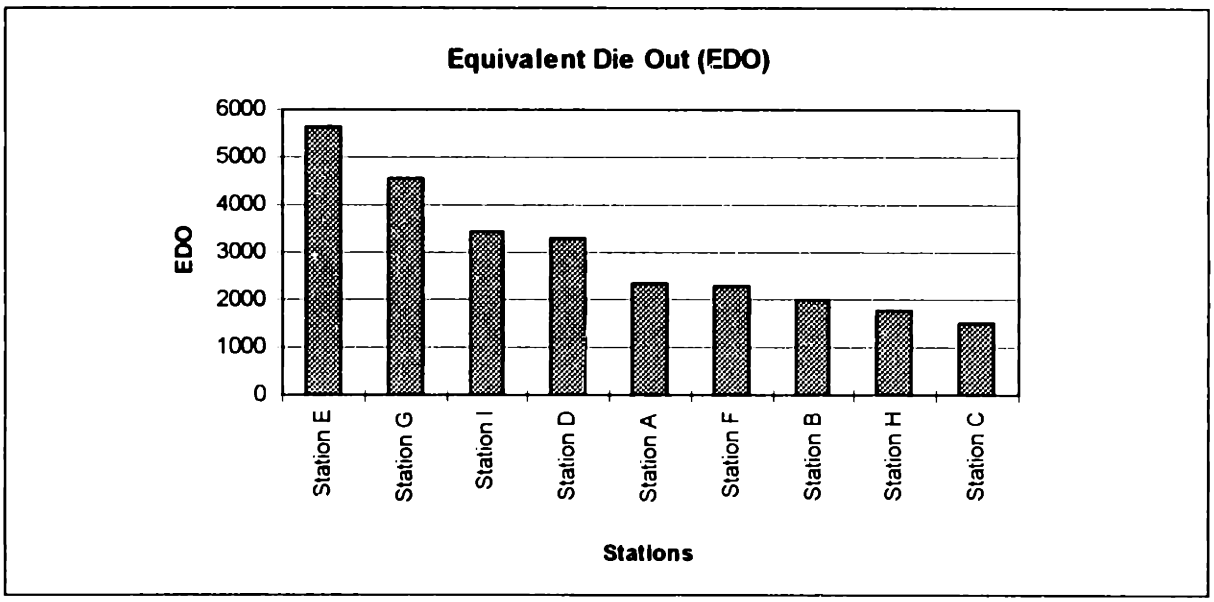
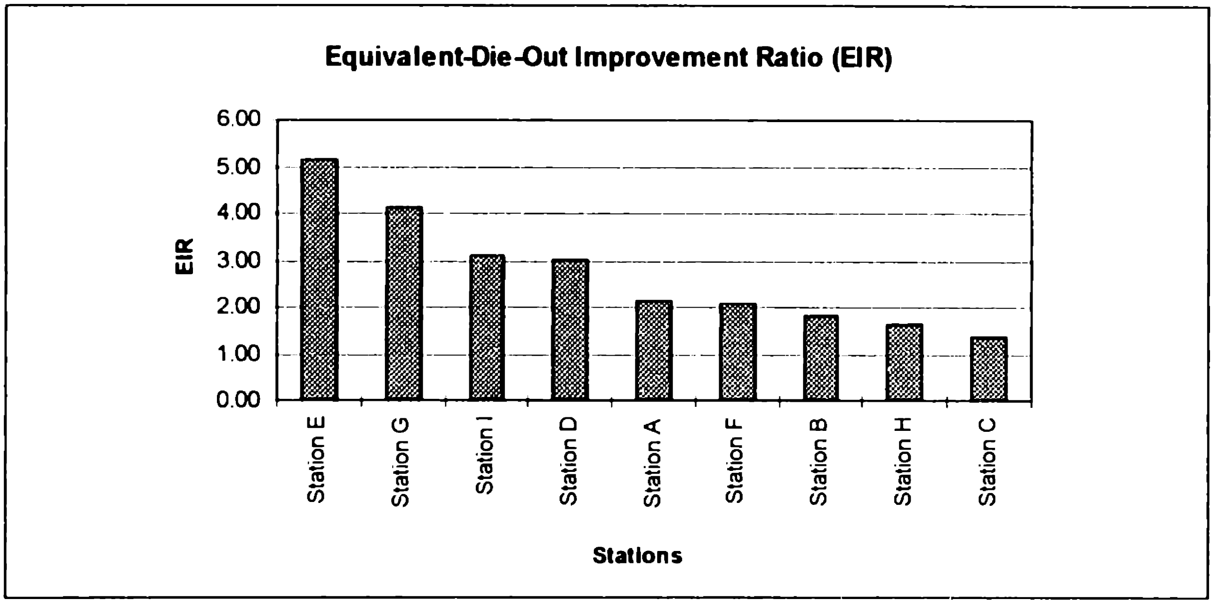


Figure 2.8 EIR Graph Example



EIR makes an improvement over EDO in that the calculations are easier to perform. EDO values are difficult to calculate because the calculation needs to take into account product mix, capacity, and other factors. Fortunately for EIR, many of the factors that are necessary for EDO calculations cancel out in the numerator and the denominator.

The importance of these methods is not necessarily predicting precise improvement numbers. Even with a wide margin of error, they provide a general picture of which stations need the most amount of engineering attention. The engineering teams are able to concentrate their resources on the top pareto items. The graphs have been produced on a quarterly basis and distributed to engineering management and teams for high priority identification.

Historically, these methods have not always transferred well from one virtual factory to the next. The transfers have been heavily dependent on the people who happened to know these methodologies from their past experience.

In general, EDO is not popular amongst those who must calculate the numbers and make the graphs because of the complexity involved in the calculation. Because EIR is the newer method of the two, it requires some learning curve on the part of both graph generators and the engineers who will utilize the information. Neither EDO nor EIR have been officially transferred to the latest virtual factory.

All projects are tracked and communicated via a project management template. This template tracks five pieces of information for each project: project category, name, project level, projected gain, and implementation date. Project level is an internal rating, one to five, for projects based on the potential impact of the project. The project management templates are presented at a quarterly engineering meeting to assess the projects being pursued. New projects can be added or current projects can be removed from the template as new opportunities for improvements arise.

2.5 Evaluation of Current System

This section evaluates the current prioritization system described in the previous section. In general, the engineering teams' efforts result in meeting goals. Somehow the right things seem to be getting done. However, most of the managers and engineers feel that the process of achieving these goals can be quite painful. What engineering teams hope for is confidence that they are working on the right set of projects to meet the high level priorities set by the engineering management.

The wafer fabrication manufacturing environment is information rich. It is difficult sometimes for both engineering management and engineering teams to analyze all the information efficiently to direct engineering efforts. Even though all the necessary information may be available to the engineering teams, difficulties arise in choosing specific areas of improvements. For example, both die yield and run rate improvements can increase output. The trouble comes in knowing which one would provide a higher return. Engineering managers and engineers expressed during interviews that they were not sure what areas to improve in order to achieve the largest gain.

Engineers and engineering managers shared during interviews that high level priorities are fairly clear; however, the detailed lower level priorities can be uncertain. For example, a high level priority may address increased output as one of its top goals. But, output can be increased in several ways: improvements in yields, increasing equipment run rate, reducing test wafers, etc. Because it is not necessarily clear to each engineering team which areas of improvements would increase the output the most, they usually initiate a high number of projects leaving room for inefficiency.

Lacking a clear formal prioritization system introduces several problems. Total dependence on the current way of communication paths, through periodic group meetings or one-on-ones, can be slow and inefficient. Much time can be wasted in gathering and in deciphering information. In addition, the current approach is too dependent on the initiative and willingness of those individuals in the support groups who are responsible for communicating priority information.

The bits and pieces of information received from the support groups at different times do not necessarily provide a clear big picture for the factory. Most engineering managers and engineers expressed frustration during interviews about not having a global picture of the areas to improve for the entire virtual factory. The engineering management oversees around two dozen engineering teams. Because there is not a common set of information from which the list of projects being pursued by the engineering teams can be evaluated, the engineering management is often frustrated. The engineering teams frequently pursue as many projects as possible to cover all possible goals. The end result is inefficiency in both resources and time, lack of confidence in decision, and lack of understanding of the overall status of the virtual factory.

A survey of the engineering team leaders has shown that most of the engineering teams use multiple methodologies to choose a set of projects. The most common methodology was intuition or judgment based on past experience. The use of multiple methodologies can be effective, but this causes some confusion at the engineering management level and in intra-department or intra-team communication. Everyone is using something different. A quick survey of the engineering teams indicated that several methods have been found as being used at one time or another. These methods are EDO/EIR, Cost of Ownership, Failure Mode Evaluation Analysis (FMEA), and intuition.

Project tracking templates, used by the engineering teams, do not ask for all the pertinent information required to evaluate projects. Typically, engineering teams track their projects on a template. The current project management template separates projects by risk. It does not require tracking of project cost information. Thus, translating from project cost to budgeting for engineering projects is not easily supported. The inputs to the template have not been standardized. When the templates of about 10 engineering teams were sampled, there were over 30 different project categories when these categories could have been narrowed down to about 10. In addition, for gain information, different input types existed for projects in categories.

When engineering teams complete projects, the result from the projects are not tracked. Information on past projects may not serve immediate needs, but when history of projects is lost the engineering teams can lose valuable information. Information from past projects could help determine risk of similar projects. Also, it can provide insights to the amount of gain that can be expected from similar type of projects.

Based on evaluating the current project prioritization system certain requirements could be drawn. The new prioritization system should build on past methodologies as much as possible. Familiarity of the system will be important to the buy-in process for two reasons. A familiar system will require less time to learn and people will be more comfortable with it. Because the engineering management and teams are extremely busy, if a new system requires too much time to learn then people will be too tempted to continue with their current way of operating. Thus, the new system should be built into an already existing organizational structure and business process. Also, existing data should be utilized as much as possible.

The system needs to provide a "big picture" of the factory status. Consolidation of all the pertinent prioritization information for the entire virtual factory is needed. The consolidated prioritization information should contain a summary and enough detailed information for the engineering management and team to derive a resource allocation plan.

The project management template needs to track additional pieces of information about projects. The template needs to ask for financial information and clear project schedule dates. Also, the template needs to standardize inputs to the project management template so that all communications will be clear.

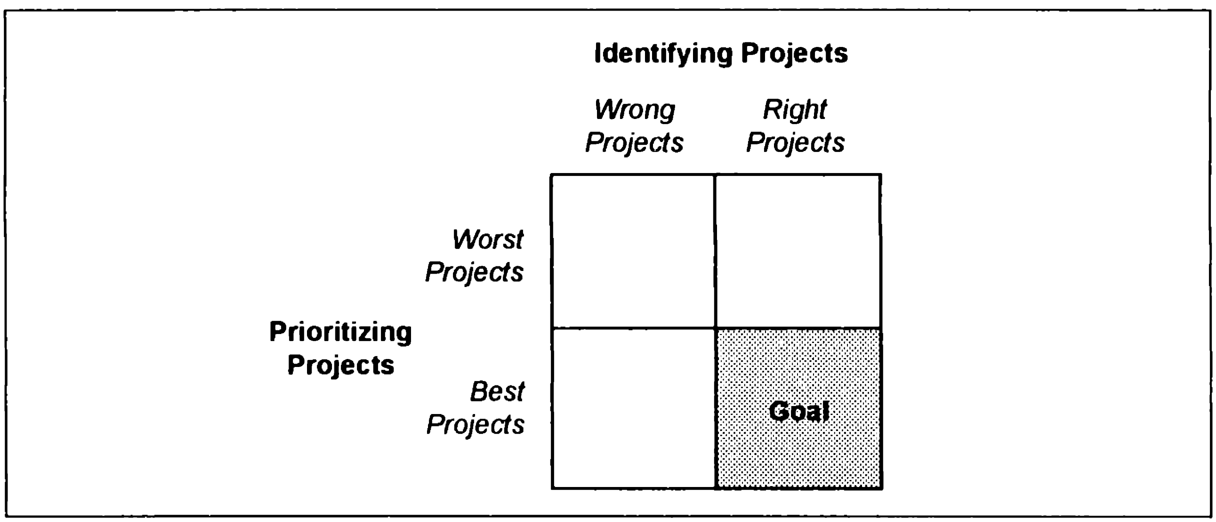
3. Project Prioritization Study

Numerous project prioritization methodologies were identified and examined to determine whether any of these methodologies can be useful in the Intel wafer manufacturing environment. Prior to examining these methodologies, an ideal prioritization system and a set of criteria were defined to help identify the most effective methodologies.

3.1 Ideal Prioritization System

An ideal project prioritization system helps to choose the highest return projects. An ideal system has two components: project identification and project prioritization. As it can be seen in figure 3.1, examining the extreme cases, the right or wrong set of projects can be identified. At Intel, engineering teams need help with identifying opportunities because the manufacturing process is too complex for them to determine opportunities on their own as described earlier in section 2.4 (Current Prioritization System). From the projects identified, the best or worst set of projects can be chosen. Thus, the goal is to identify the right set of projects and choose the best projects from it.

Figure 3.1 Project Prioritization Quadrant



3.2 Criteria

A set of criteria was chosen to help make the new project prioritization system applicable to Intel wafer fabrication manufacturing. It will serve as a useful guideline for developing a new project prioritization system. The criteria selected is based on "Project Management: A Managerial Approach" by Jack R. Meredith and Samuel J. Mantel, Jr. [1985]. The new system is to be realistic, capable, flexible, easy to use, and cost effective. These criteria fit wafer fabrication manufacturing because if any one is violated then it would be a large hindrance to implementation. Table 3.1 lists and describes each of the criteria.

Table 3.1 Project Prioritization System Criteria

Criteria	Description
Realism	• Reflects the reality that decision makers face (e.g. limitations, risk, etc.). • Common measurement system for all types of projects.
Capability	• Intelligent enough to deal with multiple inputs. • Identifies relevant inputs. • Optimizes decision.
Flexibility	• Results are valid within the range of expected conditions. • Ability to be easily modified or to be self-adjusting in response to changes in conditions.
Ease of Use	• Short execute time, including data collection and set-up time. • Not complicated or perceived as complicated.
Cost	• Cost of set-up will be negligible. • Cost of any resource to maintain and utilize the methodology will be negligible.

3.3 Study of Prioritization Methods

The objective of the study is to help determine the best methodology for the new project prioritization system. This section will describe each of the methodologies considered and evaluate their usefulness for Intel wafer fabrication manufacturing.

Jack R. Meredith and Samuel J. Mantel, Jr. [1985] define three types of methods for project prioritization: non-numeric, profit numeric, and scoring numeric methods. Numeric methods attempt to quantify the project worth based on quantified input variables. Numeric methods can be divided into profit numeric methods and scoring numeric methods. The profit numeric methods quantify the project worth in monetary value (i.e. $). The scoring numeric method quantifies the project worth in dimensionless score. Non-numeric methods do not use numbers as inputs, instead the inputs may be either subjective or objective. These three methods and their attributes are captured in table 3.2.

Table 3.2 Categories of Project Prioritization Methodologies

	Positives (+)	**Negatives (-)**
Non-Numeric Methods	• Goal oriented and directly reflect the primary concerns of the organization. • Non-economic factors can be evaluated. • Multiple criteria can be evaluated.	• Non-quantitative and credibility is often questioned. • Project with different objectives are difficult to compare. • Inputs can be subjective.
Profit Numeric Methods	• Direct financial contribution of project can be measured. • Operational value can be reasonably understood. • Project with different objectives can be compared.	• Input terms, including non-economic factors, must be expressed in dollars. • Tendency to be strongly biased toward the short-run. • Interdependencies of projects is difficult to measure.
Scoring Numeric Methods	• Non-economic factors can be evaluated. • Project with different objectives can be compared. • Multiple criteria can be evaluated.	• Outputs are dimensionless, relative measures. • Inputs can be subjective. • Tendency to include too large of a number of criteria.

There are numerous articles, books, and research papers on the topic of project prioritization. Twenty project prioritization methods were found and grouped into one of the three categories described earlier. Numerous examples of project prioritization methods exist for each one of the categories. Below is a list of projects that are most commonly known to the industrial and academic organizations. Table 3.3 lists different type of methodologies studied during background research.

Table 3.3 Methodologies by Category

Non-Numeric Methods	Profit Numeric Methods	Scoring Numeric Methods
Comparative Benefit Models	Activity Based Cost Accounting	Checklist and Profile Chart
Competitive Necessity	Benefit-Cost Ratio	Decision Tree
Decentralized Hierarchical Modeling	Cost of Ownership	Failure Mode Effects Analysis
Operating Necessity	Internal Rate of Return	Frontier Model
	Net Present Value	Linear Programming
	Options-Based Evaluation	Scoring Models
	Payback Period	Equivalent Die Out (EDO)
	Return on Investment	EDO Improvement Ratio (EIR)

Tables 3.4, 3.5, and 3.6 provide a listing of methodologies and their descriptions. These methodologies were studied to help choose a methodology that will help identify and prioritize the right set of projects.

Table 3.4 Non-Numeric Method

Method	Description	(+)	(-)	Intel Fab Use
Comparative Benefit Models	Hierarchy of projects is achieved by branching down projects into grouping of +'s and -'s, until each sub-group has minimal number of projects.	Directly compares all the projects to each other.	Difficult to differentiate projects with similar worth or value.	Engineering team members can many projects are must do projects. Some projects will be difficult to group. Discussions could get time consuming.
Competitive Necessity Model	Projects that will help maintain the firm's position with the competing firms are chosen.	Identified projects are strategically important to the company.	This category tend to get abused because many projects can be competitive necessity.	Projects that will help Intel maintain market share can be identified. Output improvement or cost savings oriented projects could belong in this category.
Decentralized Hierarchical Modeling	Parties to the decision dialogue via computer terminals until a consensus portfolio is reached.	Iterations ensure the inputs of each decision maker.	Decision can be gated by an individual or a group being too slow to respond.	This method would benefit all the engineering team members that are in different sites. Discussion of each project will be limited. Can get time consuming, because people can respond at leisure.

Operating Necessity Model	Projects that must be completed in order to continue the system operating are chosen.	Identified projects yield high leverage for receiving resources.	This category tends to get abused because many projects can be operating necessity.	Projects that could impact continuous operation of the factory can be separated. These could be environmental projects that EPA is enforcing or safety related issues that endanger lives.

Table 3.5 Profit Numeric Models

Method	Description	(+)	(-)	Intel Fab Use
Activity Based Cost Accounting	Focuses activities as fundamental cost object.	Able to track labor costs.	Output is cost based so benefit calculation is done separately.	Labor can be tracked, however, other costs, such as investments, are not tracked.
Benefit Cost Ratio	Ratio of total dollars in benefits divided by the ratio of total project cost.	Wide range of factors that determine project value is included.	No information is provided on possible range of outcome.	Ratios can be dangerous because they do not indicate the benefit amount or costs involved.
Cost of Ownership	Cost per unit produced over the life of a system can be calculated.	Investments are compared by investigating many aspects of cost, avoids making decisions based on initial cost only.	Output is cost based so benefit calculation must be done separately.	Already being used by some of the engineering teams. It allows for machine down time, present and future labor needs, and investments.
Internal Rate of Return (IRR)	Discount rate at which investment has zero net present value.	Direct comparison to the opportunity cost of capital can be made.	Choosing among mutually exclusive project can be misleading.	Rates can be calculated for Intel wafer manufacturing, however they can be misleading because they do not show time frame or the amount of benefit.
Net Present Value (NPV)	Project net contribution to wealth.	Estimates of both uncertainty and costs of delay are combined.	NPV of short-term projects will have lower numbers.	Low margin product fabs are using NPV to justify projects. Direct dollar contribution to the company can be calculated. Issue is the length of time in the future for decision consideration.
Options-Based Evaluation	Financial options theory is utilized to evaluate risk and value of projects.	Operational and strategic values can be captured.	Theory is not well understood by the masses.	Useful for investment decisions. It is not suitable for yield projects because some inputs would not relate to issues at hand.
Payback Period	Amount of time a project takes before cumulative forecasted cash flows equal the initial investment.	Favors projects that minimize up-front costs and maximize near-term benefits.	Tend to accept too many short-lived projects and too few long-lived projects.	Different types of projects can be compared, such as die yield improvement vs. machine down time. Machine down time is $ invested and die yield improvement is future benefit.

Return-On-Investment (ROI)	Productivity of an investment defined as income divided by book value of investment.	Return of the entire project is indicated.	Timing duration of investment return is not taken into consideration.	Rates can be calculated for Intel wafer manufacturing, however, they can be misleading because they do not show time frame or amount of benefit.

Table 3.6 Scoring Numeric Models

Method	Description	(+)	(-)	Intel Fab Use
Checklist & Profile Chart	Projects are subjectively rated on the basis of different criteria.	Simple.	Complex issues may be overlooked.	Categories could be weighted in favor of management's priorities. Priorities for equivalent projects will be difficult to set.
Decision Trees	Sequence of projects are represented by outcomes. The most optimal sequence is chosen in terms of success probability.	Evaluates a series or sequence of interrelated projects.	Only evaluates risk and return factors.	Risk and return information would provide much needed information, however it does not cover enough breadth of analysis needed to make an intelligent decision.
Failure Mode Effects Analysis	Investigating and assessing solutions to problems then prioritizing these solutions.	Prioritize projects that can lead to solution to a problem.	Can be time consuming and rigorous.	Helpful to distinguish solutions. However, it does not evaluate the necessary resources.
Frontier Model	The projects are plotted to show their relative risk verses return.	Useful for examining return-risk trade-offs among numerous projects.	Only evaluates risk and return factors.	Risk and return information would provide much needed information, however it does not cover enough breadth of analysis needed to make an intelligent decision.
Linear Programming	Optimizes the expected benefits to be realized from a portfolio of projects while recognizing limits on the available resources.	Handles large problems involving several projects and resource constraints.	Cannot handle the interdependencies that occur in many projects.	Resource allocation is not straight forward because there are several variables. LP would introduce an extra level of complication that may not be worth the incremental benefit.
Scoring Models	Projects are scored by summing weight and score of each criterion.	Weights can be modified according to changing conditions.	Model development is informal.	Categories could be weighted in favor of management's priorities. However priorities for equivalent projects will be difficult to set.
Equivalent Die Out (EDO)	Maximum capacity based on improvements for each station in the process is calculated.	Each station in the process can be ranked based on potential capacity improvement.	Difficult to calculate.	Was used by some of the past virtual factories.
EDO Improvement Ratio (EIR)	Ratio of maximum capacity versus current capacity is calculated based on improvements for each station in the process.	Each station in the process can be ranked based on potential capacity improvement. Easier to calculate than EDO.	Ratios do not indicate what improvement to expect.	Currently being used by one of the virtual factories.

4. Standardized Measurement

As described in section 3.1 (Ideal Prioritization System), an ideal project prioritization system will help identify and prioritize projects. For Intel wafer fabrication manufacturing, an ideal prioritization system should focus on identifying output improvement opportunities to help maximize capacity. This section describes the factors considered for choosing the most appropriate measurement methods and the actual measurement methods chosen for the new project prioritization system.

4.1 Factors for Choosing Measurement

From the corporate perspective, deliberate steps are being taken to benefit from the reward gained by increasing microprocessor production, as described in section 2.1 (About Intel). Because of this aggressive growth strategy, Intel fabs are pressured to maximize capacity. However, the maximum capacity a microprocessors fab can produce is limited by its capability. These limitations include fab space, the number of pieces of equipment that can be installed, equipment performance, and the number of people a facility can support.

Of course no fab operates at its full capability. Therefore, it is the job of each fab to maximize its capability as much as possible. This means that the fabs have to identify all capacity enhancement opportunities possible and make suitable improvements. The type of projects that can directly increase the capacity are die yield, line yield, and output capability projects. Typically, these types of projects dominate the project lists of the most engineering teams. Thus, the new project prioritization system needs to have a solid methodology to identify improvement opportunities for die yield, line yield, and output capability.

4.2 Measurement Selection

Each of the key categories was given a standardized measurement by which all the engineering teams would be guided. The key project categories were safety, ergonomics, environmental, die yield, line yield, output capability, test wafer, labor productivity and automation. Nearly all projects generated and executed belong to one of these nine categories. Similar categories have been grouped into three main topics, which are: 1) Environmental/Health/Safety (EHS), 2) Output, and 3) Strategic. Table 4.1 lists the project categories with the related main topic along with the type of standardized measurement.

Table 4.1 Nine Project Categories and Their Topic

Main Topic	Project Category	Standardized Measurement	Type of Information
EHS	Safety	*none*	List
	Ergonomics	*none*	List
	Environmental	*none*	List
Output	Output Capability	EIR	Pareto Graph
	Die Yield	EIR	Pareto Graph
	Line Yield	EIR	Pareto Graph
Strategic	Test Wafer Reduction	Test Wafers/Week	Pareto Graph
	Labor Productivity	Direct Labor Hours/Week	Pareto Graph
	Automation	*none*	List

Ideally, it would be advantageous to have a common measurement method for all nine categories. However, it is nearly impossible to find a common measurement that would allow an accurate side-by-side comparisons of these categories. The focus is not to force a common measurement for all these different categories. The measurement purpose is to reflect, as accurately as possible, the status of each one of these categories such that the engineering management and teams can simply assess improvement opportunities.

4.2.1 Measurement for EHS Projects

EHS projects, safety, ergonomics and environmental categories were not assigned measurements. Creating a measurement requires quantifying health or regulation related consequences. Projects in these categories are of the highest priorities for the factory, thus they will be pursued at all times. Thus, the engineering management and teams become interested in the EHS issues as they occur, and in addition the support groups can provide adequate EHS priority information without requiring measurements.

4.2.2 Measurement for Output Projects

In fab, the majority of the projects are geared to increase capacity. The project prioritization system must first and foremost help identify the maximum potential for increasing capacity. Because Intel enjoys a high demand for microprocessors, revenue is strongly correlated to the volume produced. For the measurement related to capacity, all the project methodologies in section 3.3 (Study of Prioritization Methods) have been evaluated to choose the most effective methodology.

The non-numeric method is not feasible because non-quantitative evaluation can be too imprecise. Wafer manufacturing is too complex to rely on human judgment without a greater dependence on quantitative evaluation. Intel, as a corporate culture, relies heavily on data when making decisions. In an environment where "buy-in" is critical to implementation, able recommendation without quantitative data or analysis will likely be declined. Judgment without quantitative support is simply too risky.

Although the profit numeric method can help assess the "bottom line," with Intel's capacity constraint situation in wafer fabs, financial measurements are not practical. This is because the return from investments can be over estimated. In an environment where the end result of a project is difficult to assess, it is difficult to have faith in financial measurements.

Even for a $1 million project, a high costing project, to increase one die per wafer improvement can more than justify the cost. This is a typical result: (1 chip/wafer) x (2000 wafers/week) x (52 weeks) x ($300/chip) = $31.2 million. Return-on-investment (ROI) of such a project is calculated at 3,120%. On the other hand, estimates could easily be ½ chip/wafer or ¼ chip/wafer increase and still result in an ROI levels of 1,560% and 780 % respectively. Thus, the wide range and the unusually high levels in ROI makes judgment difficult.

Therefore, financial measurements are unrealistic. A small increment in volume, due to an improvement, can justify for the cost. In an environment where it is difficult to make precise calculations on project output increases, using financial measurement leave too much room for error. More over, calculations can be difficult due to the complexity introduced by product mix and quickly changing prices.

The scoring numeric method has the highest potential. In a fab environment, capacity measurements are most pragmatic. Capacity opportunities could be measured and ranked for each station. Of those in the scoring numeric method, EDO and EIR show the greatest promise. The rest of the scoring methods either rely too much on human judgment or do not directly address capacity concerns.

EDO and EIR methods measure the "gap" between maximum capacity possible and the current capacity performance for each station. This translates to opportunity measurement for increasing output. Logically, the largest gap leads to the area that needs to be addressed.

EDO and EIR works well with output capability planning. Capacity goals exist for each piece of equipment. Even bottle neck stations are chosen and planned. Thus, EDO and

EIR can simply measure the difference between the goal and the current performance levels of the equipment. As long as the equipment performances meet the goals, the factory is expected to produce the planned capacity.

Out of EDO and EIR, EIR was chosen. It was chosen for several reasons. Some of the engineers were already familiar with EIR from their experiences in past virtual factories. Those in the support groups that are responsible for generating the information for the prioritization packet knew how to calculate EIR. Also, EIR is much easier to calculate than EDO as mentioned in Section 2.4 (Current Prioritization System).

4.2.3 Measurement for Strategic Projects

The strategic projects are not in an immediate need for prioritizing because these projects have a longer time horizon. The strategic projects, in general, are pursued as key opportunities are found. Also, these projects are usually part of an on-going effort. A direct measurement against improvement opportunities in EHS or Output categories is not critical.

Each of the strategic projects, test wafer, labor productivity and automation categories, is unique. Test Wafer measurement is related to the uses of test wafers per equipment cluster. Labor Productivity category is related to the required operation and maintenance labor hours. By reducing the number of labor hours required for operating equipment, productivity of each headcount can increase. Automation category has a list of the required automation projects ranked by its priority.

5. System Description

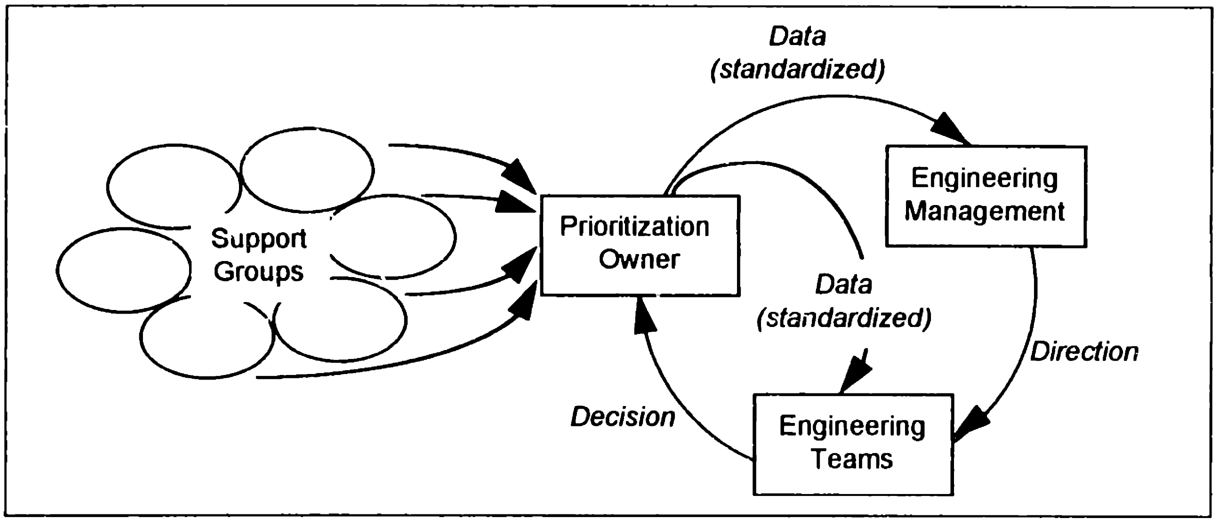
To develop the new project prioritization system, extensive interviews were conducted with numerous managers and engineers on the current situation and what they felt was needed in a new project prioritization system. A group of managers from process engineering and support groups were involved with the development to help shape the new prioritization system. This involvement was helpful in making the system realistic and useful. They will be one of the extensive participant and user of the system. The management team provided the buy-in necessary for implementation to take place.

5.1 System Overview

The new project prioritization system attempts to bring *the right information to the right people at the right time* for making effective decisions on directing engineering resources. To accomplish this objective three action items were undertaken: define roles and responsibilities; standardize communication; and define tool for prioritization. First, the roles and responsibilities of different groups within wafer manufacturing organization were defined. Defining roles and responsibilities sets specific expectations on what information will be communicated to whom when. Second, project tracking and measurements were standardized for smoother communication. Third, deliverables, which will be used as tools for prioritization, were defined.

The system has three main participants; the engineering management, the engineering teams, and the prioritization system owner. The interaction between the three participants of the prioritization system are shown in figure 5.1. The prioritization system owner is responsible for providing prioritization data by collecting information, generating graphs, assessing the information, generating packets and distributing them. The engineering management is responsible for over seeing the prioritization system and providing direction for the engineering teams. The engineering teams are responsible for tracking and executing all projects and modifying projects based on the direction set by the engineering management.

Figure 5.1 New Project Prioritization System Process Flow



The three main participants create of a feedback loop to track changes and react to changes as necessary. To begin, the prioritization system owner consolidates prioritization information. This information becomes a tool for engineering management to help set a clear direction. Based on the direction, the engineering teams modify their current plans and make decisions on how to accomplish the new priorities. Once the engineering teams make decisions, they will proceed with the projects on hand. Some time later the support organizations will measure and assess their responsibility in manufacturing and send a new set of priorities to the prioritization system owner. The cycle repeats.

The role of the prioritization owner is a central one. In the manufacturing environment, there is an over abundance of information being generated. The prioritization owner's responsibility is to consolidate only the critical pieces of information needed by the engineering management and engineering teams to make timely decisions regarding priorities.

5.2 Project Management Template

The project management template has been changed to improve planning and tracking of projects. Three areas of improvements have been made. The new template tracks information pertinent to evaluating projects and communicating project information. The priorities of the projects are tracked by project type and not by risk of project success as previously done. All the inputs to the templates have been standardized for improved communication. Each of these changes are discussed in more detail below.

The information tracked by the project management template has been modified. The project management template is shown in figure 5.2. The new project management template tracks five pertinent pieces of project information: project level, risk level, cost, projected gain and schedule. Risk level, cost and project length have been added to the previous template. Risk level is determined by the engineering team members based on their assessment of the likelihood of project success. It becomes an indication for engineering test and project verification required. High risk requires an extensive test process to ensure that the project has been implemented correctly. Low risk, on the other hand, would require no test. Cost is the total expense and capital cost per equipment.

Figure 5.2 Project Management Template

Projects			Proj Level	Risk	Projected	$ Cost	Project Length	Implementation Date			Notes
#	Category	Name	(1,2,3,4,5)	(H, M, L)	Gain/Downside	(Exp + Cap)	(Weeks)	Fab A	Fab B	Fab C	
Critical Projects											
1											
2											
3											
4											
5											
Continuous Improvement Projects											
1											
2											
3											
4											
5											
6											
7											
Binned Projects											
1											
2											
3											

The projects priority is tracked according to its project type. Because safety, ergonomics and environmental projects are considered the highest priorities for manufacturing, these projects belong to the "critical projects" section. Projects from the other categories are considered "continuous improvement projects." "Binned projects" are those that are being considered for future implementation.

The project management template, when completed, provides a platform on which a general ranking of projects can be performed. The project inputs have been standardized. All projects are labeled under one of the nine categories. Those few projects that do not belong to any of these categories will be labeled as miscellaneous. Other inputs, such as gain, risk level and project length also have standard inputs. Because inputs have been standardized, all the projects can be grouped in various ways. It is desirable to group projects because some support groups would like to review all the projects related to their group. For example, the yield engineering group sometimes needs to review all die yield projects.

In order to track completed projects, the project record template has been created. As shown in figure 5.3. The template allows a side by side assessment of projected and actual inputs. The record of past projects can be used to predict gains of future projects, track improvements, and help determine risk levels of certain project types.

Figure 5.3 Project Record Template

Completed Projects			Proj Level	Risk	Projected	Actual	Projected $ Cost	Actual $ Cost	Projected Proj Length	Actual Proj Length	Projected Implementat'n Date			Actual Implementat'n Date		
#	Category	Name	(1,2,3,4,5)	(H, M, L)	Gain/Downside	Gain/Downside	(Exp + Cap)	(Exp + Cap)	(Weeks)	(Weeks)	Fab A	Fab B	Fab C	Fab A	Fab B	Fab C
1																
2																
3																
4																
5																
6																
7																
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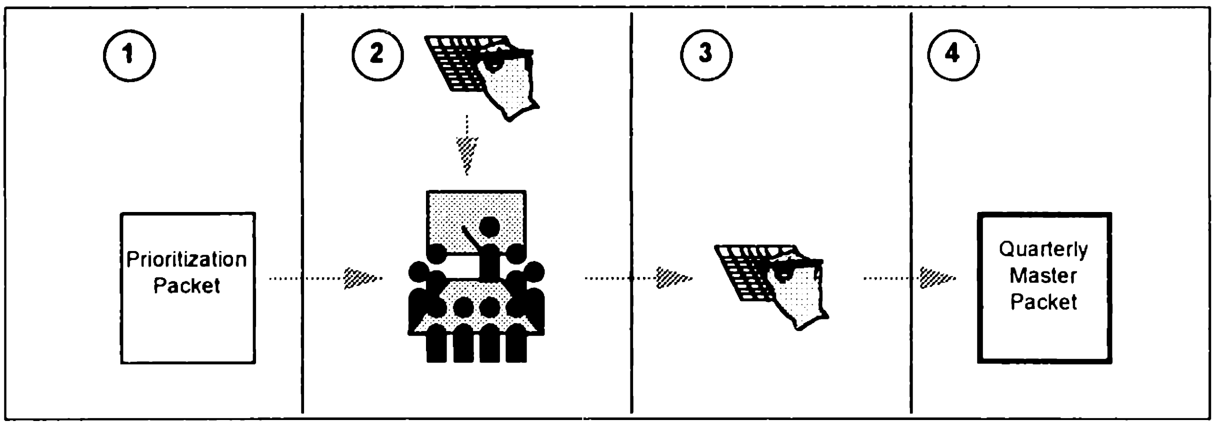
12																

5.3 Project Prioritization System

The new project prioritization system entails four major steps: prioritization packet generation, prioritization assessment, project revision, and master packet generation. Figure 5.4 shows the steps of the new project prioritization system. First, the prioritization system owner generates a prioritization packet. Second, the priorities are discussed during a quarterly engineering meeting. Third, the engineering teams can modify their list of projects if their current lists do not adhere to the priorities indicated in the prioritization packet. Fourth, the prioritization system owner consolidates both prioritization packet and the lists of engineering projects and generates a quarterly master packet. The quarterly master packet contains a summary of priorities and the projects being pursued. These four steps are examined in greater detail below.

Figure 5.4 Different Steps of New Project Prioritization System



5.3.1 Prioritization Packet Generation and Distribution

The project prioritization system owner is responsible for generating the prioritization packet. The prioritization packet is a consolidation of prioritization information from support groups representing the nine project categories. Prioritization information outside of these nine categories, such as finance and quality and reliability, will be provided as necessary. The packet will become a tool for engineering management and teams to assess currently planned projects and to plan ahead for future projects.

The prioritization packet contains a summary section and a detail section. The summary section highlights key priority information for project categories. The detail section goes in-depth on each of the priority highlights. The summary section is useful for both engineering management and teams for a quick overview of at the factory priorities. The summary contains the top several priority highlights as defined by the support groups. Figure 5.5 shows the format for the summary section. The detail section provides insights that will help the engineering teams identify projects. Figure 5.6 shows the format for the detail section.

Figure 5.5 Summary Section Format

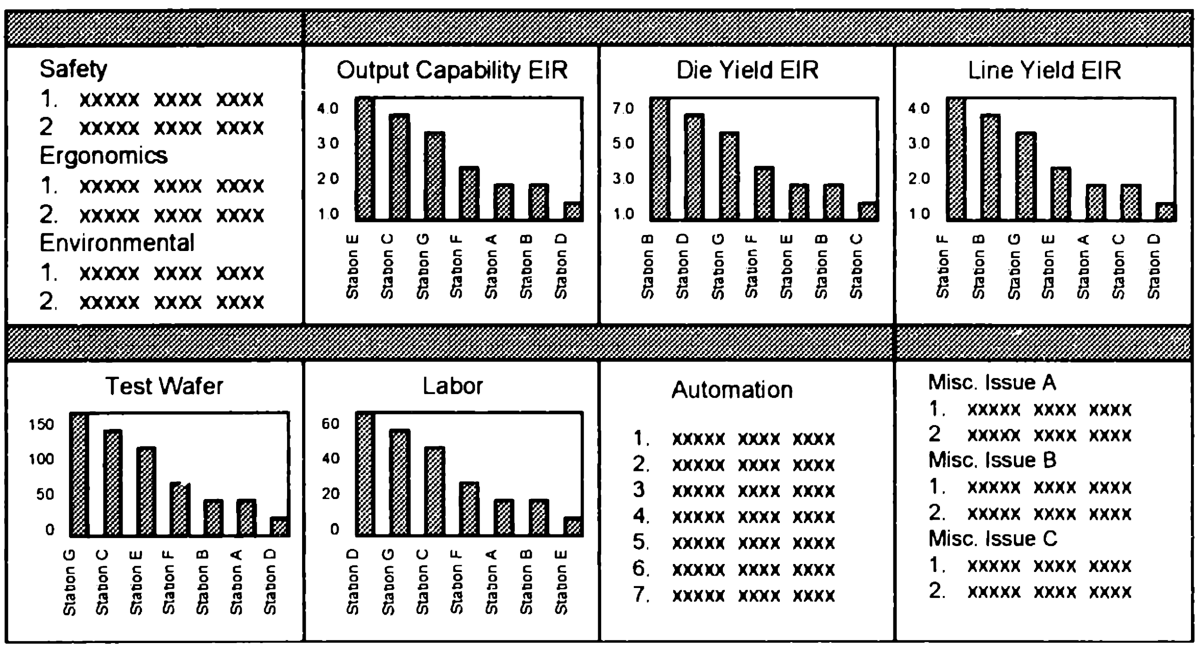
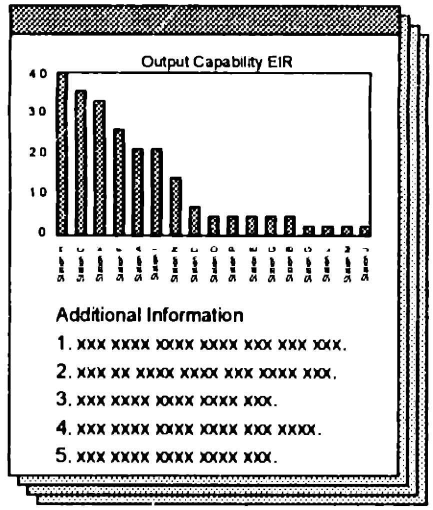


Figure 5.6 Detail Section Format



The prioritization packet is careful not to direct engineers to work on one category over another. It is a mere tool to give a snapshot of the factory status. By evaluating the prioritization information of all the pertinent parameters side-by-side, the engineering management and teams can make decisions based on factory priorities.

The system has an owner assigned to each one of the project categories. The owners are from one of the support groups to engineering. Each owner is responsible for sending the prioritization information to the prioritization system owner. The prioritization packet becomes the opportunity for support groups to "sell" their priorities to the engineering teams. For example, the industrial engineering group monitors the progress of output capability parameters such as run rates and availability. If some stations are below the projected metric then the industrial engineering group can use the prioritization packet as a forum to emphasize certain priority items.

The project prioritization packet is to be presented during the quarterly engineering meeting. During this meeting, all the current and planned projects for each one of the engineering teams will be assessed against the prioritization information given in the packet.

5.3.2 Prioritization Assessment

Routinely, the engineering team representatives meet with the engineering management around the mid-point of each quarter. There are many items discussed during these meetings and among these is the review of the list of projects being pursued by the engineering teams.

It is in this meeting that both engineering management and teams have a chance to evaluate the list of projects against the priorities indicated in the prioritization packet. If the projects do not align well with the opportunities indicated in the prioritization packet, then new projects need to be identified. If any unnecessary projects are found, then they are dropped from the list of projects.

5.3.3 Project Revision

The project prioritization packet indicates at the first level that there are gaps between potential opportunities and projects being pursued. The gap is simply the opportunities for improvement versus the amount of engineering effort placed already to resolve the opportunities. For example, if a station was identified as one of the top ten stations for die yield improvement, the station needs to have the projects to make die yield improvement for the station. The judgment is more qualitative than quantitative because potential gain information for projects have a large margin of error.

In order to meet the priorities set based on the prioritization packet, the engineering teams modify their list of projects. The engineering teams can then generate a new set of projects or drop unnecessary projects.

5.3.4 Master Packet Generation and Distribution

The purpose of the master packet is to help the engineering management and teams to prioritize and track projects until the next master packet is generated about a quarter later. When the engineering teams have finished revising their list of projects, they send their updated project management templates to the prioritization system owner. The system owner combines and summarizes both the prioritization packet and the list of projects indicated on the project management templates.

The master packet contains a summary of all the projects, prioritization packet information, projects by category, and projects by engineering teams. The summary of projects contains a break down of projects by implementation dates, by categories, and by risk. This section is presented in graphs for a snapshot view of projects. The prioritization packet contains the same information as the one that was published for the quarterly engineering meeting. Also contained are the listings of projects by category and projects by engineering teams. The master packet can have different sets of information added or deleted as necessary. For example, a list of projects by cost can be added if budgeting concerns arise.

6. Prioritization System in Use

This section describes the actual implementation experience for this project. It also runs through two fictitious scenarios to illustrate the use of the system from both the engineering and engineering management perspective.

6.1 Implementation

The goal of this project was not only to develop a working project prioritization system but also to follow through with a full implementation. Implementation provides a valuable opportunity to receive feedback on the new project prioritization system. There were four steps involved in this implementation.

1. Convince all the engineering teams to use the new project prioritization template.
2. Generate the project prioritization packet for review during engineering quarterly review.
3. Generate the master quarterly packet for engineering management, engineering teams and support group members.
4. Select a permanent prioritization system owner.

6.1.1 Project Management Template in Use

The buy-in process for the new project management template was brief. Most found that the template was useful because it helped them track information that they can use to rank their projects. Each engineering team is required to track all their projects on a template, and engineering team leaders are responsible for maintaining the template.

Because most the engineers were not used to tracking project background information with much discipline, primarily due to their hectic schedule, engineers were slow to fill out all the inputs. Largely because the engineering teams were not required in the past to keep a thorough record of the projects being pursued and did not develop a habit of tracking all the information.

With the new project management template, the engineering teams are asked by the engineering management to fill out the templates completely. The information from the template will be used for the quarterly master packet. The plan is to build in enough flexibility to the master quarterly packet such that the projects can be assessed according to the inputs such as cost, implementation date, etc.

6.1.2 Prioritization Packet in Use

The prioritization packet was available for the engineering management and team members at the quarterly engineering meeting. Most engineering teams were curious whether they were pursuing the opportunities indicated by the prioritization packet. The EIR pareto graphs, which showed improvement opportunities by station for die yield, line yield, and output capability, were most useful to the engineering teams because much of their efforts have been geared toward increasing capacity.

Surprisingly, the current list of projects matched well with the priorities listed in the prioritization packet. The engineering teams were basically attacking the improvement opportunities that they should be with only a few exceptions. The prioritization packet information provided confidence that they were generally working on important projects.

There may be two reasons that the engineers appear to be working on the right projects. First, the manufacturing environment is information rich, thus, the engineers have had enough information to cover a wide range of improvement opportunities. Second, the improvement opportunities during the early phase of manufacturing are fairly standard. At the time of implementation, the virtual factory was between start-up and ramp-up phases.

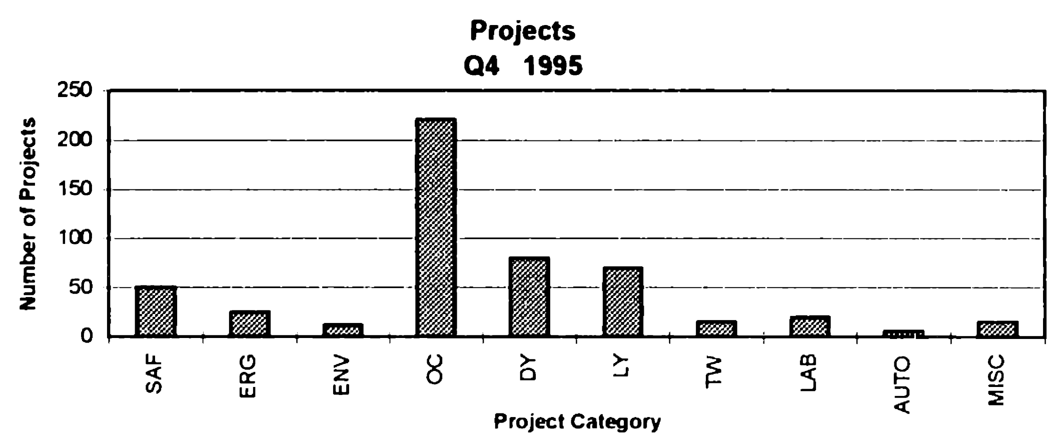
The prioritization packet benefited the engineering management greatly because they were able to see the improvement opportunity summary for the entire virtual factory. Engineering management found the summary section to be most useful because it provided a "snapshot" of the improvement opportunities in the virtual factory.

6.1.3 Quarterly Master Packet in Use

Once all the project management templates were updated as necessary, they were all sent to the project prioritization owner. The project information, along with the prioritization packet, were used to generate the quarterly master packet. The quarterly master packet will serve as a key management tool until the next quarterly engineering meeting.

The project summary section provided useful information. Figures 6.1, 6.2 and 6.3 show example graphs from the project summary section. The numbers indicated in the graphs have been disguised due to confidentiality concerns. However, we can generally see the usefulness of these graphs. For example, figure 6.1 indicates that most of the project efforts are being focused on output capability (OC). If the prioritization information indicates that output capability is a very high priority, then in general, the virtual factory projects are in tune with the priorities.

Figure 6.1 Projects By Categories Graph from Quarterly Master Packet



Note: All numbers are fictitious due to confidenitality concerns.

Figure 6.2 Projects By Risk Graph from Quarterly Master Packet

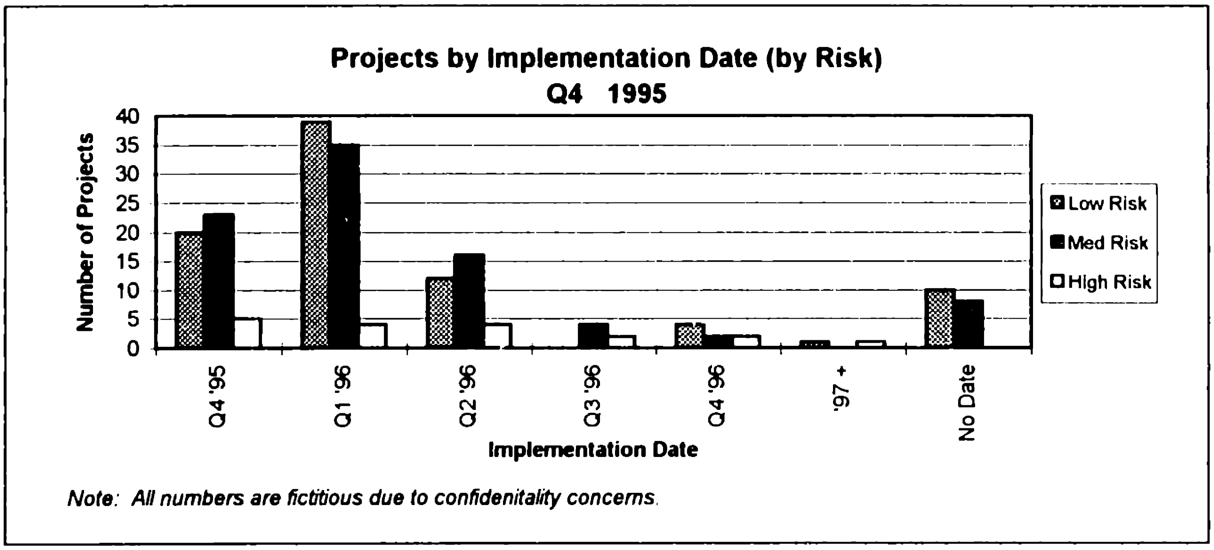


Figure 6.3 Projects By Implementation Date Graph from Quarterly Master Packet

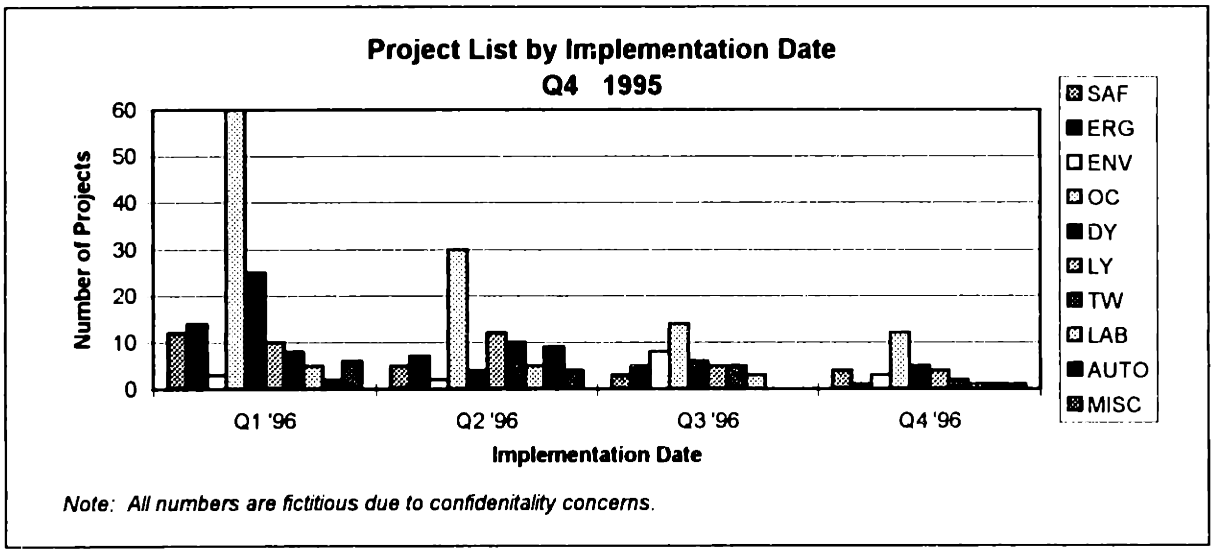


Figure 6.2 provides a general "heads up" for those groups who are responsible for supplying engineering tests for every project rated as medium (M) or high (H) risks. Figure 6.3 provides a look at the number of short-term projects versus long-term projects.

6.1.4 Prioritization System Owner Selection

A project prioritization system owner was chosen by the engineering management. The system owner will play an important role, and is responsible for managing the entire prioritization system. This includes coordinating the support groups to generate information in the right format at the right time. Also, the owner is responsible for generating both the prioritization packet and the quarterly master packet.

6.2 Prioritization System in Use Scenarios

The following are two hypothetical scenarios describe how the project prioritization system will be utilized by engineering team members. Two examples have been selected: die yield and environmental projects are used in the scenarios. The problems and the type of equipment described are illustrative only, and do not reflect the manufacturing facility in which this internship took place.

6.2.1 Die Yield Project Scenario

The die yield project scenario describes how an engineering team might use the new project prioritization system to detect and resolve a die yield problem. The project attempts to eliminate a particle problem in a metal deposition. Particle problems are one of the most common types of issues that reduce die yield for semiconductor products in general. The project takes place in Station E where metal deposition is performed.

The project prioritization system requires the support groups to provide prioritization information by the mid point of every quarter. The information is sent to the prioritization system owner who publishes the prioritization packet. The packet is reviewed during the quarterly engineering meeting to assess whether the projects in place by all the engineering teams meet the priorities indicated by the packet.

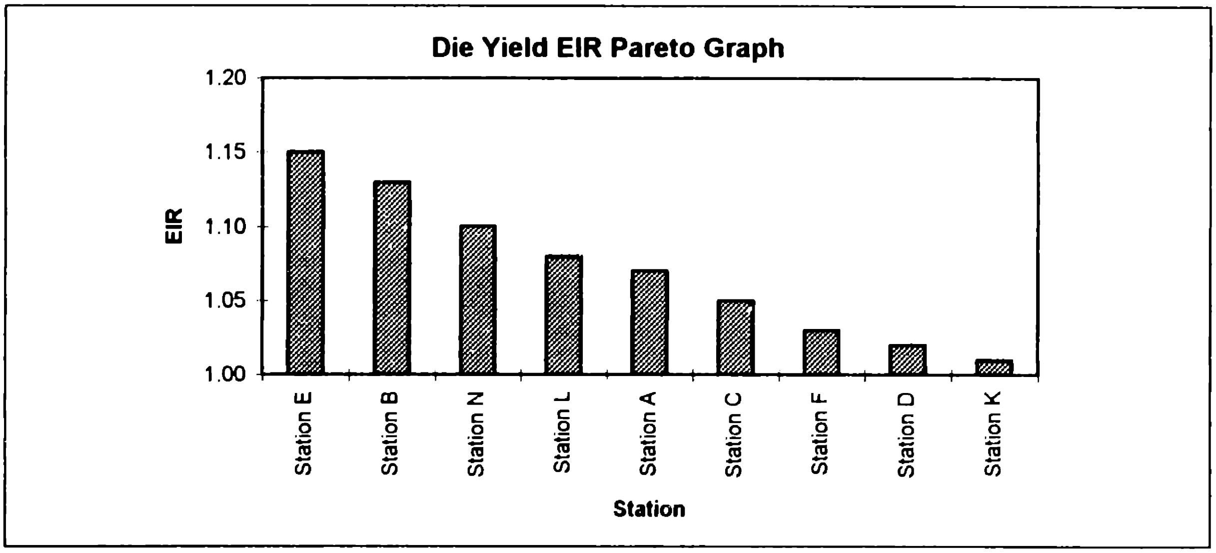
For die yield, the yield engineering group provides the priority information to the prioritization system owner. The priority information that the yield engineering group generate is a die yield EIR pareto graph. An example of the graph is shown in figure 6.4. In order to create the die yield EIR pareto graph, the number of failures the process is contributing, in terms of die/wafer, for each station in the process must be known.

The failure contribution for each station is known through failure analysis performed on defective die. The yield engineering carefully examines each die layer by layer. Once a problem is known, then the failure is assigned to the most likely station from which the problem has occurred. Failure analysis does not guarantee perfect results. However, it is a good estimate for assigning failures to stations. Failure analysis is not performed on all defective die. Each analysis is extremely arduous and time consuming. In most cases, wafers are sampled.

Once each station is characterized in terms of its contribution of failures, EIR calculations can begin. Assume 40 pieces of die went through failure analysis. Stations E and B were assigned the most number of failures. Five were assigned to Station E and four were assigned to Station B. 12.5 % of failures are caused by problems in Station E and 10 % of failures are assumed to be caused by problems in Station B. The percentage of failures and capacity information are used to calculate die yield EIR for each Station. These EIR values are then arranged into a pareto graph, and presented as in figure 6.4.

The die yield EIR pareto graph is sent to the prioritization system owner by the yield engineering group. The prioritization packet is generated once the prioritization system owner collects all the priority information from the support groups. The packet is distributed at the quarterly engineering meeting so that it is available for the engineering teams to assess their list of projects against the priority information.

Figure 6.4 Example of Die Yield EIR Pareto



For EIR graphs, as discussed in Section 2.4 (Current Prioritization System), the stations with EIR values greater than one indicates opportunity for improvement. For die yield, not all stations with EIR values greater than one will pursue die yield improvements. Depending on the yield for the entire virtual factory or an individual fab, the management will decide how many of the stations indicated by the EIR pareto graph will pursue die yield improvements. The top several stations in the EIR pareto graph are usually asked by the engineering management to pursue die yield improvements. For this scenario, assume that stations E, B, N, and L have been chosen to significantly reduce the die yield problems.

The EIR values are ratios of total capacity that could be gained, if all the problems were resolved, versus the current capacity. Thus, the EIR value of 1.15 for Station E can be translated as a total of 15% capacity increase opportunity. Similarly, 1.13 value for Station B can be translated as a total of 13% capacity increase opportunity.

Since Station E has been identified as having one of the highest levels of opportunity for die yield improvement, the engineering team for Station E assesses whether its current projects are sufficient to significantly reduce its die yield problems. Upon consulting the yield engineering group, the engineering team concluded that the current list of projects is inadequate. The yield group showed that there are five die/wafer defect count for station E, but there is only one die yield project in place and it is estimated at reducing the defect count by 0.25 die/wafer at best.

Yield engineering group is again contacted for information regarding failure analysis results. Out of five failures assigned to Station E, three of them were caused by a metal particle problem. Upon a series of experiments on the deposition equipment, the engineers found slight shifts in pressure that occur periodically inside the pressure chamber. Even though the shifts seem to be within the specification, the pressure change seemed to contribute to the problem.

At an engineering team meeting, several proposals are discussed among the engineering team members to resolve the pressure shift. The most feasible solution seems to be replacing a part in the deposition equipment which appears to be the culprit in causing the pressure shift. A project to replace a part in the chamber is agreed by the engineering team members. The project is given a name for identification, "Part Replacement."

Once the project was agreed by the engineering team members, it needs to be approved by two groups of people: integration engineering and engineering management. The integration engineering group evaluates projects from the entire process view point. Since many of the steps in the process are interdependent, they assess how a project, once completed, will affect the rest of the process. The engineering management reviews for project logistics or any large issues that would make any project not feasible.

The integration engineering group also helps in assigning project level and risk levels. The project level is determined by standard criteria set by Intel manufacturing. The level is based on how much a project would alter the wafer fabrication process. The highest level means that customers need to be informed about the changes that are about to take place in the fabrication process. The lowest level means that the project will not alter the fabrication process at all. Of course, the project level assigned to a project can change as the project progresses because unforeseen consequences are always possible.

The risk level is based on the amount of engineering test necessary to make sure that the project has been implemented successfully. Risk is based on the likelihood of the project being implemented successfully and the level of interdependence a project would have on other steps. If a project is considered a high risk, then a full set of tests is planned. Tests could involve test wafers and end of line testing which involves packaged tests under burn-in stress. Some projects require no test.

For the "Part Replacement" project, the project level of "3" and a risk level of medium, "M," has been assigned. Replacing a part in the deposition equipment should not alter the process enormously. After all, the pressure shift observed had been within the specification. The risk level of "M" is assigned because the new part will help make the specification more tight. A yield problem due to replacing the part is very unlikely.

The project is assigned resources and is ready to be listed in the project management template. As described earlier, the project and risk levels have already been assigned. The next steps are to calculate potential gain, estimate the expected cost of the project, determine the project length and implementation dates.

Accurate gain information is extremely difficult to calculate for die yield because there are so many factors that affect the result of a project. First of all, the result of the failure analysis are not totally accurate. Thus, the defective die/wafer value to begin with is not totally accurate. Also, getting rid of all defects on a die yield project is extremely difficult.

As mentioned earlier, three die/wafer were assigned to the chamber pressure problem. During a brief experiment, the new part was found to reduce the defect density of particles by about half. Using the results from the test, some past experience, and "good engineering judgment" as the basis, a gain number was calculated at 1.5 die/wafer.

Cost information was easily calculated by summing expense plus capital per piece of each equipment. The cost of the part that has to be replaced is $10,000. An additional $5,000 per piece of equipment is required for engineers from the vendor to provide service and training. The total cost for upgrading each piece of equipment is $15,000.

Next, the project length and implementation dates was determined. The project length depends on availability of the part and the engineering resources available. The implementation date depends on when the project begins. The "Part Replacement" project should be considered an extremely important project. Recovering about 1.5 die/wafer will contribute significantly to capacity. A project of this magnitude would be requested by the engineering management to have it finished as quickly as possible. The shortest time in which this project can be completed is eight weeks. It would take this long for the parts to be delivered and installed and for the required tests to be completed. The implementation date is eight weeks after the start date for all the fabs in the virtual factory.

When all the information is available, the project is entered into the project management template. An example is shown in figure 6.5. Once the project is entered, the information on the template can be used to rearrange the projects according to urgency or importance. The project management template, once updated with all the project information, is sent to the prioritization system owner so that the quarterly master packet can be generated.

Figure 6.5 Project Management Template for Station E

Projects			Proj Level	Risk	Projected	$ Cost	Project Length	Implementation Date			Notes
#	Category	Name	(1,2,3,4,5)	(H, M, L)	Gain/Downside	(Exp + Cap)	(Weeks)	Fab A	Fab B	Fab C	
Critical Projects											
1	xxxxxx	xxxxxxxxxxxx	x	x	xxxxx	xxxxxx	xxxxxx	xxx	xxx	xxx	
2	xxxxxx	xxxxxxxxxxxx	x	x	xxxxx	xxxxxx	xxxxxx	xxx	xxx	xxx	
Continuous Improvement Projects											
1	xxxxxx	xxxxxxxxxxxx	x	x	xxxxx	xxxxxx	xxxxxx	xxx	xxx	xxx	
2	Die Yield	Part Replacement	3	M	1.5 die/wafer	$15K/tool	8 weeks	45	45	45	
3	xxxxxx	xxxxxxxxxxxx	x	x	xxxxx	xxxxxx	xxxxxx	xxx	xxx	xxx	

The information for the "Part Replacement" project, along with all other projects listed in the project management may change as necessary. Unsuspected delay or changes circumstances can occur. Upon completion of the project, the engineering tests are performed to make sure that the "Part Replacement" project has been implemented successfully. If the project has been successfully implemented, then the engineering tests should indicate significant reduction in metal deposition control problem. This result should eventually be indicated in the next prioritization packet by a lower die yield EIR value for Station E.

6.2.2 Environmental Project Scenario

The environmental project scenario describes how a hypothetical environmental problem was resolved in the prioritization system. The example environmental project involved eliminating Volatile Organic Compound (VOC) emission caused by a solution used for wiping. The project takes place in Station C.

Environmental projects are primarily initiated by the environmental engineering group. The environmental engineering group constantly monitors various emissions and alerts the engineering teams responsible the stations that generate unacceptable levels of pollutants. The objective of the environmental engineering group is to make sure that the Intel fabs meet or exceed any federal or state pollution standards. They also monitor the use of natural resources, such as water, in order to conserve as much of the natural resources as possible.

Whenever an environmental problem is detected, it is assigned to the station or stations that are responsible for the problem. The problem in this scenario stems from the use of a certain solution for wiping that adds to the VOC content emission. This solution is used for wiping the equipment and the nearby areas. As the solution evaporates, it gets sucked into a vacuum which is built to maintain a high air quality in the fab for the fab workers. All the vapors and emissions, eventually, leave the factory as emissions.

The initiation of projects to resolve environmental problems would not normally wait until the prioritization packet is generated and distributed. So, the environmental engineering group would contact the engineering team for Station C right away. The packet will help point out whether Station C needs more resources, since Station C is responsible for eliminating the environmental issue along with many other priority issues.

The environmental engineering group contacts the engineering team for Station C to propose a change to the solution currently being used for wiping. Two options are proposed: the first option is to improve the scrubber and the second option is to replace the solution. Replacing the solution is agreed upon by the engineering team members because it will take less time and the cost will be lower. The project is initiated and goes through a process of approval similar to that of the die yield project scenario given in the previous section. A name of "Solution Change" is given for this project.

Because all safety, ergonomics, or environmental projects are considered the highest priorities, environmental projects should be approved by the engineering management quickly. The integration engineering should approve the project quickly since the change in solution for wiping should not affect the process at all.

The "Solution Change" project would receive a low risk, "L," rating and a project level of 5 because no change to the process is expected. Gain is simply reduction of VOC. Since the environmental engineering group felt that 2% of the total emission was coming from the solution used by Station C, the project proposed will replace the old solution with the one that will not contribute at all to VOC. Thus, a 2% reduction is expected. The cost is $50,000 for eliminating the existing solution and purchasing the new solution. The project length is four weeks because of the expected product delivery time. Since the change will need to take place immediately in order to reduce the VOC level right away, the implementation date for all the fabs is four weeks from the current date. Figure 6.6 illustrates the "Solution Change" project entered into the project management template for Station C.

Figure 6.6 Project Management Template for Station C

Projects			Proj Level	Risk	Projected	$ Cost	Project Length	Implementation Date			Notes
#	Category	Name	(1,2,3,4,5)	(H, M, L)	Gain/Downside	(Exp + Cap)	(Weeks)	Fab A	Fab B	Fab C	
Critical Projects											
1	xxxxxx	xxxxxxxxxxx	x	x	xxxxx	xxxxxx	xxxxxx	xxx	xxx	xxx	
2	Environmental	Solution Change	3	L	2 % VOC reduction	$50K/tool	4 weeks	48	48	48	
Continuous Improvement Projects											
1	xxxxxx	xxxxxxxxxxx	x	x	xxxxx	xxxxxx	xxxxxx	xxx	xxx	xxx	
2	xxxxxx	xxxxxxxxxxx	x	x	xxxxx	xxxxxx	xxxxxx	xxx	xxx	xxx	
3	xxxxxx	xxxxxxxxxxx	x	x	xxxxx	xxxxxx	xxxxxx	xxx	xxx	xxx	

The project management template serves as a communication and planning tool. Once the project information is in the template, the environmental engineering group and the engineering management can recognize that the project is in place. As environmental projects are given the highest priority, some other projects may be pushed aside until the "Solution Change" project is completed. The information for the projects in the template can be used to rearrange identify those projects that can be momentarily set aside.

If the problem was eliminated, then on the next prioritization packet this VOC problem would be removed. Since the environmental engineering group constantly monitors the emission levels, they can easily update the prioritization system owner for the next distribution of the packet.

7. Conclusion

A working project prioritization system has been developed and implemented. A network of people has been established, including a permanent prioritization system owner, to provide consolidated and standardized prioritization information to the engineering management and team members.

The new project prioritization system meets the criteria discussed in Section 3.2 (Criteria). The new system is easy to use, from the engineering management and team view point. Also, it is cost effective. The project prioritization system owner is a part time responsibility. There were no purchases of equipment or software for the new system. The system is flexible because the information can be arranged in various ways to meet different needs. It is also realistic and capable.

The longevity and the effectiveness of the new project prioritization system will heavily depend on the project prioritization owner. The project prioritization system owner is responsible for not only ensuring timely delivery of the prioritization packet and the master packet, but making continuous improvements to the system. Also, the owner is responsible for transferring all the working knowledge to the new owner.

In the future, the project prioritization owner could potentially evaluate and recommend priorities. The owner could also perform some of the work that engineering management are involved with currently, such as evaluating current projects against the priorities indicated by the priority packet. Performing these responsibilities would a higher level of responsibility to the project prioritization owner. In addition, it would allow more time for the engineering managers to make strategic plans.

Some research questions related to this thesis topic can be identified. Under the current policy, all Safety, Ergonomics, and Environmental projects are top priorities. Perhaps some projects in these categories should not receive as high of a priority. Of course this is not to place quantitative measurement on human safety or environmental condition. However, not all projects in the Safety, Ergonomics, and Environmental categories should be receiving the amount of valuable resources.

Another research topic is studying how to build in cost reduction efforts from the early part of manufacturing stages. Cost reduction is not generally a high priority during the earlier stages of microprocessor manufacturing. Because the demand for the latest microprocessors is high nearly any effort to increase output can justify its cost. Eventually, cost reduction becomes more important issue as demand and output volume stabilizes. Decisions can be made during earlier stages of manufacturing that hinder reducing cost during the later stages. For example, during the ramp-up stage a piece of equipment could be purchased to meet the output demand. The cost of the purchase, in the form of depreciation, will last throughout the later stages of manufacturing. Cost effectiveness affects the longevity of fabrication facilities.

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