Program Management Systems for the Semiconductor Processing Capital Equipment Supply Chain

by

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Submitted to the Sloan School of Management and the
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Master of Science in Electrical Engineering and Computer Science

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Abstract

The Capital Equipment Procurement group of Intel Corporation is responsible for developing and procuring the semiconductor processing capital equipment that is used throughout all of the company's development and manufacturing facilities. The semiconductor industry is faced with rapid technology change, increase in the complexity of the manufacturing process, and high cost of capital. In this challenging environment, the group is concerned with the following two issues required to maintain their leadership position in the industry.

First is the need to evaluate risk earlier in the capital equipment specification and development cycle to ensure that the semiconductor processing capital equipment is developed on schedule (on-line, on-time) at an affordable cost. A previous model developed and used in the manufacturing readiness phase of process development serves as the basis for a new risk assessment approach. Modifications, including new risk categories, criteria, and processes enable the new model to be applied earlier, in the technology development phase.

Second is the need for a more accurate cost model to capture the costs of new processes that employ equipment from existing processes at Intel. As Intel faces increasing cost pressure on some of the new commodity products it is developing, it must increase equipment reuse in its new process designs. A target costing model is developed that first sets target and baseline costs, and then tracks progress from the baseline cost until the target cost is achieved. This model is used to closely manage various cost reduction programs or projects being undertaken in its process development organization.

The overall theme of this thesis is to demonstrate how these two program management systems can be used to manage the development of new manufacturing equipment such as needed in the semiconductor and other capital intensive industries.

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Chapter 1: Overview of Thesis

The Capital Equipment Group (CEP) at Intel Corporation is responsible for developing and procuring the semiconductor processing capital equipment used in wafer processing fabs throughout the world. In that effort, it worries about a number of issues that affect Intel's ability to maintain a one-generation lead over the competition. Of those, two were of particular concern to this thesis: First, CEP wanted to evaluate risk earlier in the capital equipment specification and development cycle than they had been to date to ensure that the semiconductor processing capital equipment is developed on schedule (on-line, on-time) at an affordable cost. This thesis takes a model Intel had developed and implemented in the manufacturing readiness phase of process development, and modifies it to be applied earlier in the technology development phase. Second, CEP wanted to develop a more accurate cost model to capture the costs of new processes when those processes employ equipment from existing processes at Intel. As Intel faces increasing cost pressure on some of the new products it is developing, it wishes to increase equipment reuse in its new process designs. Further, it wishes to closely manage various cost reduction programs or projects being undertaken in its process development organization.

The discussion of these two issues is the core topic of this thesis. However, since these issues are separate analyses, involving two separate products and requiring interaction with distinct functional groups within Intel, the thesis will be divided in two separate sections: one, addressing project risk management, and the second, addressing cost modeling for new product development. The overall theme is based upon the project cost and risk management associated with the development of a new product produced with a new manufacturing process technology. A secondary theme through these sections is to demonstrate how these program management systems can be valuable for other industries, especially those with highly complex capital intensive manufacturing processes.

Chapter 2 introduces the Intel Corporation and shows how the Capital Equipment Procurement group fits into the company in the current manufacturing environment. We also discuss Intel's product lines, process and product terminology, and the semiconductor supply chain. Finally, we review program management and how Intel uses it as a tool for competitive success.

Chapter 3 reviews the current project risk management literature and develops a general framework that is used for project risk management. This project risk management framework is then applied in Chapter 4 to the extension of an existing manufacturing risk assessment methodology earlier into the process and product development cycle. After working through the thought process of this new model, in Chapter 5 we critically analyze the project risk management system at Intel and provide potential opportunities for improvement considering the current state of the industry.

In the next part of the thesis, we transition to discussion of cost modeling as a second equipment development management tool. Chapter 6 reviews the current cost modeling literature and shows the evolution of cost models over time before focusing in on target costing. Chapter 7 discusses the product target cost methodology used at Intel and then describes the cost model that was developed during the internship for the semiconductor processing equipment that will be used to produce a new product. In Chapter 8, the cost model developed at Intel is critically analyzed and compared to current industry best practices from the literature. Several opportunities for improvements considering current industry trends are described.

Chapter 9 is the overall conclusion to the thesis as a whole, stating the key ideas and results that can be applied to other similar capital intensive manufacturing industries.

Chapter 2: The Intel Corporation and the Capital Equipment Procurement group

This chapter introduces Intel Corporation and the Capital Equipment Procurement group (CEP), which will be at the center of this thesis. To understand what CEP does, we review Intel's business, the semiconductor supply chain, the Capital Equipment Procurement group's function within Intel, the manufacturing environment at Intel in 2003, the product and process development timeline, and terminology used throughout the thesis. Finally, we review program management for semiconductor products within CEP; the importance of program management (as a way that Intel maintains its lead in the industry) and opportunities to improve the existing program management tools.

2.2 Intel Corporation

Intel was founded in 1968. After introducing the first microprocessor in 1971, it rapidly grew to its current status as a leader in the semiconductor industry. Most every computer user has heard the slogan "Intel Inside" or can recognize the Intel signature sound following television commercials from various computer manufacturers.[1] Although Intel is a Dow Jones company with 31 billion dollars in revenue in 2003,[2] it is in a rapidly changing industry with semiconductor process technologies and products becoming outdated in only two years. Intel is able to stay in its leadership position by leveraging its ability to flawlessly execute the simultaneous introduction of an initial lead product with a new generation of process technology.[3] Efficiently and effectively introducing affordable products is achieved with solid program management.

Intel Corporation designs, develops, manufactures and markets computing and communications products at various levels of integration.[4] It has three product line operating segments: the Intel Architecture business, which is composed of the Desktop Platforms Group, the Mobile Platforms Group and the Enterprise Platforms Group; the Intel Communications Group (ICG), and the Wireless Communications and Computing Group (WCCG). The Intel Architecture operating segment's products include microprocessors and related chipsets and motherboards. It is the microprocessors group

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[1] Jackson, pp. 313-316.
[2] 2003 Intel Corporation Annual Report
[3] Hayes, p. 3.
[4] 2003 Intel Corporation Annual Report

that people think of when they think of Intel. We discuss this group in the context of the risk assessment part of this paper.

ICG's products include wired Ethernet and wireless connectivity products, network processing components and embedded computing products. WCCG's products include flash memory, application processors and cellular baseband chipsets for cellular handsets and hand-held devices. We discuss this group in part two of this thesis, when we discuss cost models for High-Mix Low-Volume products (HMLV) such as flash memory. The company's products are sold directly to Original Equipment Manufacturers (OEMs), and through retail and industrial distributors, as well as reseller channels throughout the world.[5]

Within Intel, the Capital Equipment Procurement group (CEP) is responsible for developing and procuring the semiconductor processing capital equipment used in wafer processing fabs for all three product line operating segments and for all the fabs worldwide (Israel, Ireland, California, Oregon, Arizona, New Mexico, Colorado, and Massachusetts). This means that CEP works with semiconductor equipment manufacturing companies to develop new machines that have the new capabilities required to produce the next generation chips. Low-Mix High-Volume (LMHV) microprocessor products require new machines every generation since the newest rapidly changing technology is required to produce industry leading products.

The development and purchase of this equipment requires CEP to control billions of dollars. In fact, this highly specialized equipment is a major cost driver in chip prices.[6] The concurrent drop in average semiconductor selling prices and increase in product diversity is causing Intel to augment its focus on cost and risk issues in the capital equipment development and procurement process. Specifically, Intel is interested in moving its examination of cost and risk upstream in the process development process to identify issues and opportunities earlier and further ensure successful manufacturing ramps and product launches.

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[5] Ibid.

[6] Tortoriello

2.3 Semiconductor supply chain

As shown in Figure 1 below, the semiconductor supply chain begins with raw silicon ingots. After these ingots are sliced into thin wafers, they are bought by Intel and are brought to a Fab (or plant) where they are processed with chemicals on the highly specialized machines that CEP has developed and procured to make many individual devices on a single wafer. The processed silicon wafers are then transported to a chip assembly and test factory where they are tested, diced into individual chips, and assembled into packages that can be attached to circuit boards.[7]

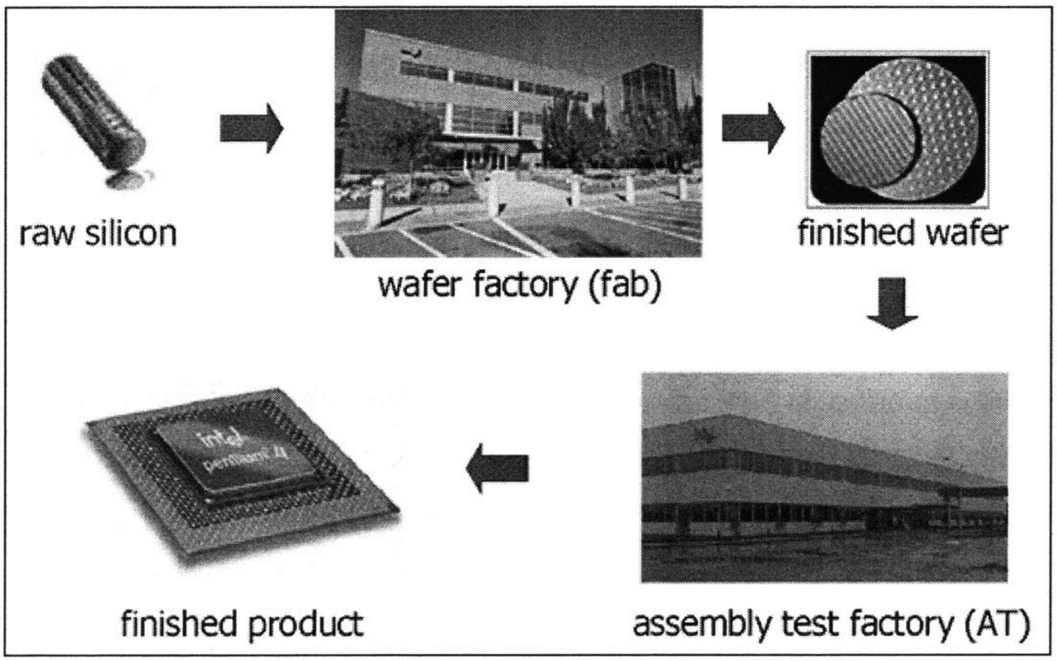

Figure 1: Semiconductor Supply Chain

Development and procurement of the machines that make the chips (the "tools") in the wafer factory or fab occurs several years before the supply chain is in operation. Equipment cost is a major portion of the total cost to produce a semiconductor. Standard & Poor's *Semiconductors* reports the following on the huge capital investments:

> Each year, semiconductor manufacturers invest significant sums of money in new plants and equipment. Currently, a state-of-the-art fabrication facility, or fab – the plant where chips are made – costs nearly $3 billion to

build. In 1984, the figure was just $10 million. According to Sematech, an industry trade group, this cost could balloon to $10 billion by 2015, making a semiconductor manufacturing plant the most expensive facility in the world – more costly than a nuclear power plant.[8]

Including cost restraints, time is also a limited resource that the Intel supply chain has to manage. Semiconductor processing is a highly complex process requiring several hundred processing steps performed on around one hundred unique semiconductor processing tools.[9] The continuation of Moore's Law, which states that the number of transistors that can be placed on a given silicon chip will double every eighteen months, causes modern fabs to be outdated in only two years.[10] Further complicating this process are the globally dispersed fabs and equipment suppliers.[11]

2.4 Capital Equipment Procurement group

As shown in Figure 2, the Capital Equipment Procurement group plays an integral role within the Intel manufacturing organization. The group's engineers and commodity managers direct information flow between suppliers, development factories, manufacturing factories and other internal departments. They are also responsible for overseeing the current supply line and creating long-term supplier strategies. Supervising variable information requires the creation of business processes that must be flexible enough to withstand changing business conditions. Despite information volatility, managing the total cost of ownership for semiconductor processing equipment and the associated affordability of individual semiconductor processes is an important function that the group must perform.

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[7] Tortoriello, pp. 14-16.
[8] Smith, p. 18.
[9] Tortoriello, pp. 14-16.
[10] *Ibid.* p.14.
[11] *Ibid.* p. 9.

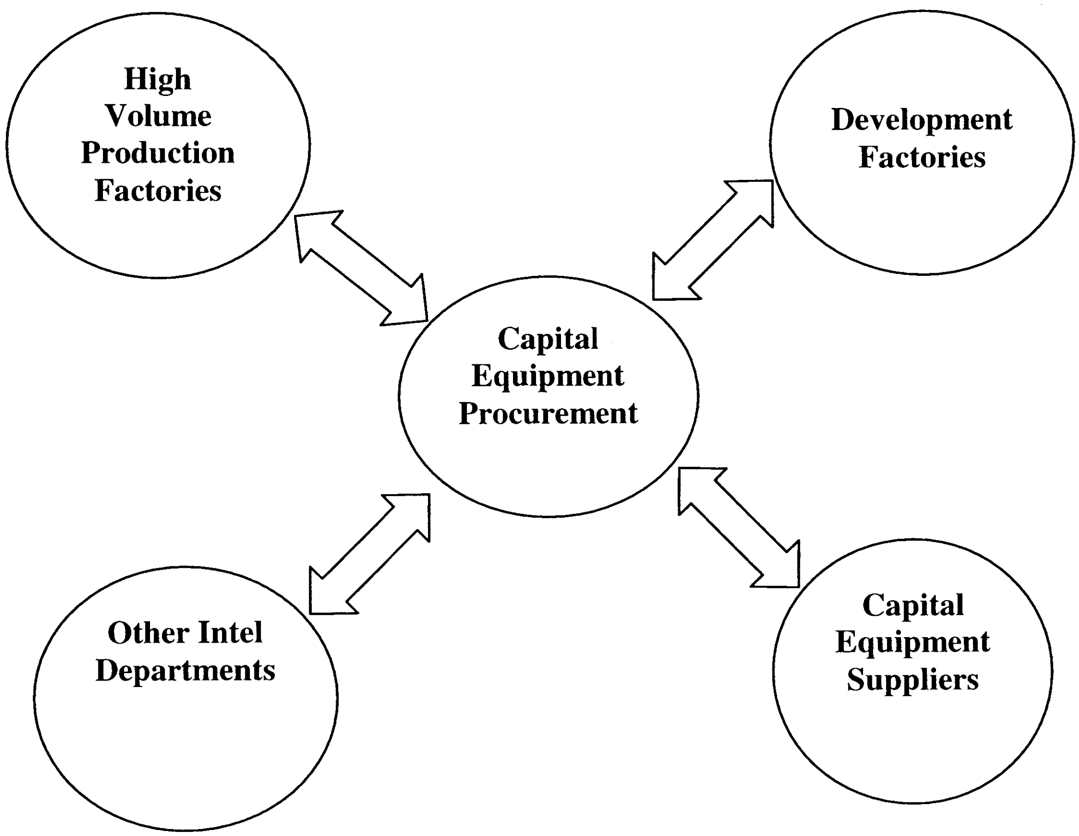

Figure 2: How Capital Equipment Procurement fits into the organization

2.5 Manufacturing environment at Intel in 2003

The semiconductor industry has historically been characterized by having high capital costs, rapidly changing manufacturing technology, highly cyclical markets and strong competition.[12] The manufacturing environment at Intel today consists of more fabs, faster product ramp times, greater cost pressure, more products and aggressive equipment suppliers than in the past.[13]

Intel developed a large network of semiconductor manufacturing fabs during a period of rapid growth in the 1990s. Today Intel owns and operates eight fabrication facilities throughout the world. This makes coordination among the development organization, all of the fabs and the capital equipment suppliers difficult.

[12] Smith, pp. 1-6.
[13] Ibid., pp. 16-24.

The average selling prices for the core microprocessor business are dropping as the prices for computers fall. This creates increased pressure to maintain low costs to sustain market leadership.[14]

Faster and steeper manufacturing ramps of new process technologies require flawless execution to obtain returns on large capital expenditures. It is imperative that all parts of the manufacturing process and the associated tools are ready to go for the ramp of a new process technology. The failure of one small part in the manufacturing process will create huge losses as expensive equipment lays idle and the competition gains ground.[15]

As Intel diversifies away from the core microprocessor business, it offers an increasingly larger number of semiconductor products. In addition to multiple different microprocessors for different market segments, Intel produces chips for wired Ethernet, wireless connectivity, flash memory, application processors, and cellular baseband chips, just to name a few.[16] This requires major changes as the company determines how to effectively produce a high mix of products produced in low volumes.

Suppliers that are under pressure to reduce new semiconductor processing equipment costs are aggressively protecting their revenue streams by increasing costs for spare parts and service for maintenance and repairs.[17] Intel must be careful to understand the entire cost of ownership when purchasing new semiconductor processing tools.

2.6 Product and process development timeline

Intel develops a new generation of process technology simultaneously with a new product. This process and product development cycle for new semiconductor products at Intel, shown in Figure 3, is broken up into sections of time.

- **Strategic enabling**: Basic research conducted with universities and suppliers to develop knowledge and technologies for future semiconductor processes.

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[14] Smith., pp. 16-24.
[15] Weber, pp. 420-426.
[16] Intel Corporation Annual Report
[17] Tortoriello

- **Pathfinding**: A proof-of-concept of the entire process and all of the semiconductor processing tools is developed.
- **Technology development**: The designs of the process, product and associated semiconductor processing tools are all finalized.
- **Manufacturing ramp**: The process and product knowledge is transferred from the development fab to the volume fab as the volume fab begins to a produce a product on the new semiconductor process technology.
- **Volume production**: Products are fully transitioned from the development factories to the production factories where they are produced in volume.

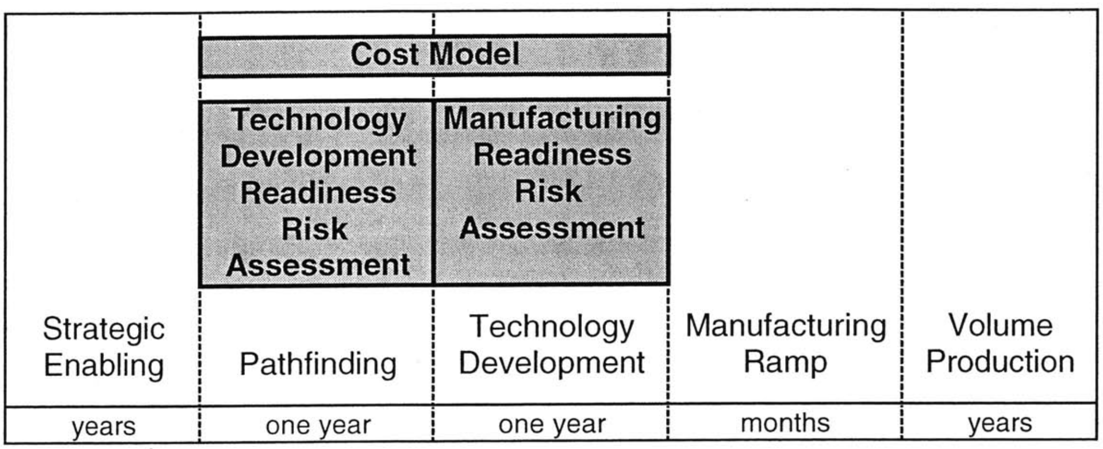

Figure 3: Product and Process Development Timeline

The majority of the resources from the Capital Equipment Procurement group are involved in the technology development stage of the product development cycle. Smaller percentages of people are assigned to the pathfinding, ramp, and production stages of development.

2.7 Process and product terminology

As a general introduction to the products and processes that are discussed in upcoming chapters, we identify in Table 1 the different products examined in this thesis, the processes used to produce them, and characterizations of the manufacturing process. Note that some of the products are High-Mix Low-Volume, while others are Low-Mix High-Volume, and that the products are in different phases of development (pathfinding or technology development). These differences will become important in later chapters of this thesis.

	Process technology		
	GEN-T	GEN-W	GEN-Q
Current phase of the development cycle	Technology development	pathfinding Y nm	pathfinding Y nm
minimum feature size	X nm	Y nm	Y nm
lead product	microprocessor	microprocessor	flash HMLV
Characterization of manufacturing process	LMHV	LMHV	flash HMLV
discussion	Chapter 4 and 7	Chapter 4 and 7	Chapter 7

Table 1: Process and product terminology

2.8 The importance of program management within the CEP

Program management is the application of knowledge, skills, tools, and techniques to project activities to meet project requirements. Program management is accomplished through the use of many different processes such as: initiating, planning, executing and controlling[18]. Within the Capital Equipment Procurement group, program management requires that all of the semiconductor processing tools be procured on time, meet process requirements, and meet program affordability objectives. Two important systems that are used to manage programs are the risk assessment methodology and the total cost of ownership affordability model.

A manufacturing readiness risk assessment methodology is currently used to ensure that all of the semiconductor processing tools will be available to successfully ramp a new process technology. This system is used during technology development to ensure that all of the tools will be procured in time to meet the ramp and that they will meet the performance requirements for the new process. The goal of this risk assessment methodology is to save valuable money and time and ensure that the project is on line, on time.

A cost of ownership affordability model is used to ensure that the costs of the machinery (over its depreciation life) 1) allow Intel to meet its target competitive microprocessor prices and 2) do not grow such that Intel's margins on chips are eroded. Producing products that are affordable is increasingly important within the current

18 *PMBOK® Guide*.

manufacturing business environment, especially with the advent of globalization and the decreasing cost of microprocessors.[19]

2.9 Opportunities to improve the existing program management tools

The existing processes within the Capital Equipment Procurement group are highly effective. However, the constantly changing dynamics of the semiconductor processing capital equipment industry require that most processes stay in an iterative state of constant improvement to maintain industry leadership. Intel identified two opportunities for process improvement that became the basis of the internship that led to this thesis:

1. Intel desires to control whether products built on new semiconductor process technologies will be manufactured according to schedule: "on time, on line." Intel requires a manufacturing readiness risk assessment model that will be extended earlier in the development cycle to assess the risk of successful completion of the technology development phase. Therefore, we developed a risk assessment methodology for the pathfinding stage discussed above (and detailed further in the Chapter 4 on risk).
2. Intel desires to better manage the price of semiconductor processing capital equipment used to create multiple different types of chips (such as flash) such that the cost of the expensive machinery will enable the production of affordable products. Therefore, a new cost model is developed to ensure cost control on equipment for the GEN-Q process used for its high-mix low-volume flash business.

[19] Smith.

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Chapter 3: Literature review in project risk management

What is the risk that we will not be on line, on time with production? How do we assess this risk early in a product development cycle? These are some of the issues that concern a program manager during the development of a new product. Assessing and responding to these issues is crucial to a new product's successful introduction into the market.[20] This is especially important in semiconductor manufacturing at a modern fab where the loss rates can exceed $10,000 per minute when production is delayed.[21]

This chapter provides a review of the literature on project risk management, and an example of risk management at a semiconductor company.

3.1 Introduction to project risk management

Project risk management is the art and science of identifying, assessing and responding to project risk throughout the life of a project and in the best interests of the project's objectives.[22] A project risk management framework will serve to structure the discussion of risk in this thesis; this framework consists of six phases: risk management planning, risk identification, qualitative risk analysis, quantitative risk analysis, risk response planning, and risk monitoring and control.[23] These will be described in more detail later in the chapter.

A company's future is determined in part by a series of judgments and decisions made within the company. Ideally, business decisions would be made in an environment of total certainty where all the necessary information is available and the future outcome of decisions can be predicted with confidence. In reality, most decisions are made without complete information resulting in uncertainty in the outcome. In the extreme case, nothing is known about the outcome and total uncertainty prevails.[24]

To introduce the concept of risk assessment, the following is a simple example.

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[20] Pritchard, pp. 1-48.
[21] Weber, p. 420.
[22] Wideman, p. II-3.
[23] *A Guide to the Project Management Body of Knowledge* (hereinafter referred to as "*PMBOK® Guide*"), pp. 127-146.
[24] Wideman, I1-I7.

3.1.1 Example to introduce the concept of risk management

Max Wideman gives this example in his book, *Project & Program Risk Management*:

> [O]ne way of avoiding a possible traffic jam while driving on the highway to a particular destination is to consider alternative forms of transportation. Granted that each may have its own particular set of risks, but careful comparison should identify the best set of alternatives with the lowest overall degree of uncertainty or risk of arriving late. However, the impact of each on the time and cost of the journey must also be taken into account if the best overall arrangement for a successful arrival is to be achieved. The selection may well depend on the relative priorities given to the cost, schedule, and quality of the journey. If the real objective of the exercise is to hold a meeting, then perhaps the opportunity could be taken to hold the meeting at a more favorable intermediate location.[25]

This example shows that there are subjective factors to risk assessment (overall quality of the journey) and there are objective factors (cost and schedule). There are also many variable factors that make predicting an outcome uncertain. For example, after quantifying the risk of avoiding a possible traffic jam, an accident on the road may occur spontaneously throwing off the risk assessment made earlier. This highlights the iterative nature of risk assessment; risk must be reevaluated at various periods on the time continuum. Further, one can make better assessments of risk if one surveys knowledgeable people. For example, in Wideman's hypothetical example, one can survey those who drive that route and avoid traffic jams, ask them what went right and what went wrong, and then change a risk assessment model based on those inputs. Finally, this example shows that information early in the process (such as checking weather forecasts before going) can help risk assessment.

Austin (2004) identifies many sources of risk that a manager has to deal with every day: financial resource risk (foreseeing cash flow shortages), human resource risk (foreseeing key employees and knowledge holders leaving a project or company), supply risk (foreseeing adequate supply and managing buffer stock) and quality risk (foreseeing compliance with standards).[26,27]

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[25] Ibid, p. I-2.

[26] Austin, pp. 101-110.

3.1.2 Risk: inevitable but manageable

Survival in today's highly competitive business environment is achieved by pursuing risky development projects with uncertain outcomes. The goals of risk management are to identify project risks and develop strategies to significantly reduce them or avoid them altogether if possible.[28]

Projects and the associated project risk factors are characterized by change throughout the project life cycle. In general, the ability to influence a project's outcome and the associated project risk is higher during the earlier stages of the product development cycle and then becomes lower during the later stages as shown in Figure 4. The amount at stake (e.g., money or resources) and the corresponding management activity (i.e., management attention to the project) typically increase later in the project development cycle. One of the objectives of risk management is to move management attention earlier in the process cycle when the greatest opportunity exists to influence the outcome at the lowest possible cost.

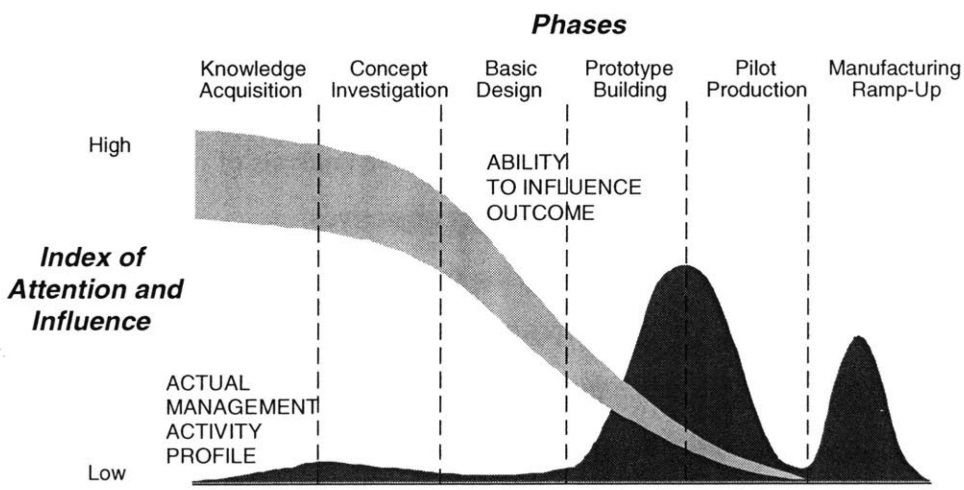

Figure 4: The timing and impact of management attention[29]

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[27] Casciano, pp. 13-15.
[28] Wideman, pp. II1-7.
[29] Henderson, p. 11.

3.1.3 Purpose of project risk management

The purpose of project risk management is to identify factors that are likely to impact the project objectives (such as time, cost, safety and quality), quantify the likely impact of each factor, and then mitigate impacts by exercising influence over items that are controllable.[30]

Project risk management should be seen as advanced preparation for possible adverse future events, rather than responding as they happen. With this advanced planning it is possible to minimize the potential problems and maximize the chance that the project objectives are achieved successfully.

3.2 Overview of six-phase approach of risk management

The Project Management Institute, the world's leading not-for-profit professional association in the area of project management, identifies a six-phase approach to project risk management:[31]

- **Risk Management Planning:** deciding how to approach and plan the risk management activities for a project.
- **Risk Identification:** determining which risks might affect the project and documenting their characteristics.
- **Qualitative Risk Analysis:** performing a qualitative analysis of risks and conditions to prioritize their effects on project objectives.
- **Quantitative Risk Analysis:** measuring the probability and consequences of risks and estimating their implications for project objectives.
- **Risk Response Planning:** developing procedures and techniques to enhance opportunities and reduce threats to the project's objectives.
- **Risk Monitoring and Control:** monitoring residual risks, identifying new risks, executing risk reduction plans, and evaluating their effectiveness throughout the project life cycle.

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[30] Pritchard, pp. 3-23.
[31] PMBOK® Guide, pp. 127-146.

Every project risk management plan is unique for each company and for each project, so a manager must evaluate the general criteria set forth by the Project Management Institute and determine what is necessary for his or her project. We now will discuss each of the six project risk phases in more detail below.

3.2.1 Risk management planning

Risk management planning is the process of deciding how to approach and plan the risk management activities for a project. There are many types of risk management techniques that are suited for diverse types of projects. Correctly matching the type of risk management to an individual project will minimize the probability of known risks adversely affecting the project's outcome while simultaneously minimizing the costs associated with the risk management process.[32] For example, managing quality risk (whether a product will be developed to specification) requires a different risk management plan than managing human resource risk (whether key employees will leave).

A risk management plan is developed by a team that includes the project manager, project team leaders, key stakeholders, and others as appropriate. This group of people develops and writes the plan by taking into account the organization's risk management policies and then tailoring these policies to the unique project needs. Often organizations have existing risk management plans and templates that are customized for new projects.[33]

The risk management plan is a written plan that describes the steps for risk identification, qualitative analysis, quantitative analysis, response planning, monitoring, and control throughout the project life cycle. There are eight different areas that may be included in the plan:

- **Methodology:** the tools, approach, and data sources that are used to perform risk management on a project.
- **Roles and responsibilities**: for all of the risk management team members.

[32] Pritchard, pp. 25-31.
[33] Ibid, pp. 25-31

- **Budgeting:** set so that the cost of risk management will be lower than the benefits derived from it.
- **Timing:** where in the project life cycle the risk management process will be used to positively affect the project outcome.
- **Scoring and interpretation:** must be determined at the beginning of the project life cycle to ensure that qualitative and quantitative risk analysis is performed consistently.
- **Thresholds**: the risk levels that will trigger a response along with how much of a response is required.
- **Reporting formats**: how the results from the risk management process will be documented, analyzed, and communicated.
- **Tracking:** how the risk activities will be documented for the current project along with lessons learned for future projects.[34]

These eight factors should be carefully considered and tailored by a manager and his or her team to customize the risk management plan to the project.

3.2.2 Risk identification

The second phase, risk identification, results in a list of risks that will potentially affect a project. This process is typically conducted by experienced personnel and requires an understanding of the project's mission, scope, and objectives. Identifying risks is an iterative process that includes input from as many different people as possible in an attempt to achieve an unbiased of an analysis as possible.[35]

Types of risk to identify

Risks that may affect the project outcome are grouped into categories: Technical, quality, or performance risk includes items such as unproven or complex technology. Project management risk includes items such as poor allocation of time and resources. Organizational risk includes items such as lack of prioritization of projects, inadequacy or

[34] *PMBOK® Guide*, pp. 127-130.
[35] Pritchard, pp. 31-34.

interruption of funding, and resource conflicts with other projects. External risks include items such as a changing regulatory environment, currency exchange rates, and country risks. The risk categories mentioned above are some of the more common risk categories, but there are many additional categories that must be considered as described below. Historical information including results from previous projects and the lessons learned should be incorporated in the development of new risk areas.[36]

Tools and techniques for identifying risk[37]

- **Brainstorming:** is performed by the project team to obtain a comprehensive list of potential risk areas. A team comes together and identifies risk areas.[38]
- **The Delphi technique:** is a way to reach a consensus of experts on a subject such as project risk.[39]
- **Interviewing:** is a technique that consists of identifying appropriate experts and then questioning them about risk in their areas of expertise as related to the project.[40]
- **SWOT:** is an acronym for "strengths, weaknesses, opportunities and threats" to a project. It looks at strengths of a projects, it weaknesses, opportunities for success and threats to its success. This is a directed risk analysis designed to identify risks and opportunities within the greater organizational context.[41]

3.2.3 Qualitative Risk Analysis

Qualitative risk analysis, the third phase of the six-phase approach, is the process of assessing the impact and likelihood of identified risks. This allows for the qualitative evaluation and comparison of the individual risks that have previously been identified.[42]

A template for a risk impact and probability rating matrix is shown in Figure 5. The impact scale shows the magnitude of the effect on the project's objective, while the

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[36] Ibid, pp. 31-34.
[37] *PMBOK® Guide*, pp. 131-133.
[38] Pritchard, pp. 115-120.
[39] Ibid, pp. 109-114.
[40] Ibid, pp. 57-64.
[41] Ibid, pp. 129-136.
[42] *PMBOK® Guide*, pp. 133-137.

probability scale shows the probability that an individual risk will occur. The scales can be broken into additional sections and do not have to be linear, but they are typically kept simple so that they show clear risk rankings.[43]

	probability		
Impact	low	moderate	high
low	low probability low impact	moderate probability low impact	high probability low impact
moderate	low probability moderate impact	moderate probability moderate impact	high probability moderate impact
high	low probability high impact	moderate probability high impact	high probability high impact

Figure 5: Risk probability and impact matrix

Risk ranking is a subjective process, so it is important that the risk rating scheme is built against an agreed upon set of criteria to help minimize discrepancies.[44] For some projects a qualitative risk analysis is sufficient to guide the risk response (e.g., if hard quantitative data is expensive to obtain and not expected to add value), but for some other projects (e.g., when quantitative data exists is readily available and expected to add value) a manager may, in his or her opinion, want to perform an additional quantitative risk analysis.

3.2.4 Quantitative Risk Analysis

The quantitative risk analysis process, the fourth phase, numerically identifies the probability of each risk, the consequence of each risk (on each project's objectives), and the risk of the project as a whole. This analysis determines which risks are most important and pose the greatest threats to the project.[45]

Some of the common tools used to quantify risks include: The *expert interview technique* consists of first identifying appropriate experts and then methodically questioning them about risks in their area of expertise. *Sensitivity analysis* is used to

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[43] Pritchard, pp. 34-38.
[44] Ibid, pp. 34-38.
[45] *PMBOK® Guide*, pp. 137-140.

determine which risks have potentially the greatest project impact. *Decision tree analysis* shows the potential impact of project outcomes by incorporating a combination of project options, the probability of the options, and the expected value of the options. *Simulations* such as Monte Carlo analysis are used to show ranges and probabilities of possible project outcomes.[46]

The output from the combination of the qualitative and quantitative risk analysis is a prioritized list of risks that pose the greatest threats to the project's outcome.

3.2.5 Risk Response Planning

Risk response planning, the fifth phase of the six-phase approach, is the process of developing procedures and techniques to enhance opportunities and reduce threats to the project's objectives. It determines what actions will be taken to address risk issues evaluated in the identification, qualification, and quantification stages.

Risk response planning strategies fall into the following categories: Risk *avoidance* alters the project plan to eliminate the condition or protect the project from its impact. Risk *transference* transfers the risk to a third party. Risk *mitigation* reduces either the probability or impact of a risk by taking a specific course of action. Risk *acceptance* is the decision to acknowledge and endure the consequences if a risk event occurs. It is the project manager's responsibility to identify the proper strategy for each individual risk.

The output from risk response planning includes a list of all of the risks, the actions required to mitigate them and assignment of ownership responsibility. It is important that all of the tasks are clearly documented along with the expected timeframe in which a response is required.[47]

3.2.6 Risk Monitoring and Control

Risk monitoring and control is the last phase of the six-phase approach, and involves monitoring residual risks, identifying new risks, executing risk reduction plans, and evaluating their effectiveness throughout the project life cycle. After the risk

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[46] Pritchard, pp. 215-223.
[47] Pritchard, pp. 41-44.

management plan is put into action it must be continually reevaluated to ensure that it is still valid for the project and thoroughly documented.[48]

There are many different methods used for risk monitoring and control. Project risk response audits are performed during the project life cycle to examine the project team's progress on identifying, assessing, and developing appropriate risk strategies. Project risk reviews are scheduled on a regular basis to determine if the risk ratings and prioritization require changes. Technical performance measurement is performed to ensure that the technical performance is advancing per the project's technical achievement plan. Additional risk response planning is required when a previously unidentified risk emerges as one that will potentially affect the project and requires a response.[49]

Effective risk monitoring and control processes significantly reduce the probability of a risk occurring by making decisions that alter the outcome before the risk occurs. These decisions can include developing alternative strategies and plans. It is important to document the events and changes that occur throughout the cycle to ensure that the organization has the opportunity to apply lessons learned during the next project.[50]

Up to this point, this chapter has outlined the importance and purpose of project risk management and summarized the six-phase approach promoted by the leading authorities on project risk management. We will now show how this phased approach has been applied at a semiconductor manufacturing company.

3.3 Project risk management at a semiconductor company

In this section, we show how the project risk management framework can be applied within a semiconductor manufacturing company. Thompson (2000) shows how risk management is combined with project management in the new product introduction process for Motorola's Semiconductor Products Sector.[51] The four phase approach taken

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[48] Wideman, pp. IV1-4.
[49] *PMBOK® Guide*, pp. 144-146.
[50] Pritchard, pp. 44-47.
[51] Thompson, pp. 49-54.

includes risk identification, risk quantification, risk response development, and risk control.

3.3.1 Risk identification

Motorola's risk identification process is most commonly accomplished with a brainstorming technique by the New Product Introduction (NPI) team, through which all of the team members identify potential risk sources without judgement or analysis. A partial simplified list of the identified risks from one of these sessions is shown in Table 2. The list was simplified in the paper to show the process, but not to show a complete list of all potential risks.

No.	Risk
1	New silicon will not function after tape out
2	Process in fab results in poor yield
3	Test program not established
4	Schedule slip due to lack of resources
5	Package problem meeting thermal perf.
6	Solder joint requirement not met
7	Burn-in Req'd for Infant Mortality

Table 2: Example results from using risk analysis tool

3.3.2 Risk quantification

Risk quantification is either qualitative or quantitative. An example of a qualitative risk ranking is shown in Table 3 where the probability and impact are both ranked on a high, medium, or low scale. The advantage of this qualitative technique is that it is simple and easy to implement. The disadvantage is that it is difficult to monitor across organizations and that it is difficult to create definitions that clearly differentiate between the various rankings.[52]

[52] Ibid., p. 51.

No.	Risk	Probability	Impact
1	New silicon will not function after tape out	high	high
2	Process in fab results in poor yield	low	high
3	Test program not established	medium	low
4	Schedule slip due to lack of resources	low	medium
5	Package problem meeting thermal perf.	medium	low
6	Solder joint requirement not met	low	low
7	Burn-in Req'd for Infant Mortality	high	high

Table 3: Qualitative analysis tool after risk identification

An example of a quantitative risk ranking including numeric probability and impact values is shown in Table 4. The probability that a risk will occur is determined with statistical data, subjective judgment, simulations, or historical data. Impact analysis can be accomplished with historical data, estimates, subjective judgement, or simulations of both cost and schedule. The advantage of a quantitative analysis is that it provides a feeling of security or knowledge. The disadvantage is that it takes additional time and the numbers can be misleading since they are all estimates, but represented as "real" numbers.

No.	Risk	Probability	Impact ($ M)
1	New silicon will not function after tape out	60%	2
2	Process in fab results in poor yield	20%	3
3	Test program not established	50%	0.5
4	Schedule slip due to lack of resources	10%	1.5
5	Package problem meeting thermal perf.	30%	0.1
6	Solder joint requirement not met	10%	0.1
7	Burn-in Req'd for Infant Mortality	70%	2.5

Table 4: Results from the quantitative analysis tool

After the qualitative or quantitative analysis is complete, the risks are ranked to prioritize which are most important and in what order to address them. This ranking is simple if the risks have been quantitatively analyzed by probability and impact, requiring the simple multiplication between the two columns in the table. In this example, risk number 7 has a 70% probability multiplied by a $2.5 million dollar impact results in a value of $1.75 million dollar impact which is larger than all of the other impacts so it is ranked as the number one priority risk to address. The rankings for this example are shown in Table 5. A similar ranking is not shown, but can be accomplished with the qualitative data by making all risks with high probabilities and high impacts the first risks to be addressed.

No.	Risk	Probability	Impact ($ M)	Priority
1	New silicon will not function after tape out	60%	2	2
2	Process in fab results in poor yield	20%	3	3
3	Test program not established	50%	0.5	4
4	Schedule slip due to lack of resources	10%	1.5	5
5	Package problem meeting thermal perf.	30%	0.1	6
6	Solder joint requirement not met	10%	0.1	7
7	Burn-in Req'd for Infant Mortality	70%	2.5	1

Table 5: Risk prioritizes from analysis tool

3.3.3 Risk response development

Now that the risks have been identified, quantified, and ranked, responses are developed for each of the risks in order of importance. Cost, complexity, time, resources, ease of implementation and which stage of the project that the risk occurs are all taken into account during risk response planning which is summarized for this example in Table 6. Three options for addressing risks are acceptance, mitigation, and avoidance. A risk is accepted and documented if it is determined that the company is willing to accept it. For mitigation and avoidance the company takes actions to reduce the probability or impact of the risks if they do occur.[53]

No.	Risk	Risk Response	Owner
1	New silicon will not function after tape out	Design review and verification before tape out	D. Kerr
2	Process in fab results in poor yield	Start back-up lots after 1st Si w/ alt. Process	M. Lowe
3	Test program not established	Test engineer report status daily to PM	C. Burnes
4	Schedule slip due to lack of resources	Assure test manager assigns engineer	K. Sullivan
5	Package problem meeting thermal perf.	Perform simulations using Theta	J. Miller
6	Solder joint requirement not met	Perform analysis on daisy chains in lab	A. Mawer
7	Burn-in Req'd for Infant Mortality	Purchase baords so they are available	J. Berr

Table 6: Risk response development

3.3.4 Risk control

An example of the final phase, risk control, is shown in Table 7. The outcome from the risk response plan is shown in the table. This status is continuously updated

[53] Ibid., p. 53.

throughout the project life cycle as the risks are minimized. The final step in the process is to create a list of lessons learned to improve the process for the next product.

No.	Risk	Risk Response	Outcome
1	New Si will not function after tape out	Dsn review and verification before tape out	N/A
2	Process in fab results in poor yield	Start back-up lots after 1st Si w/ alt. Process	Back-up lot worked
3	Test program not established	Test engineer report status daily to PM	N/A
4	Schedule slip due to lack of resources	Assure test manager assigns engineer	N/A
5	Package problem meeting thermal perf.	Perform simulations using Theta	Simulations within 10%
6	Solder joint requirement not met	Perform analysis on daisy chains in lab	Data showed no issue
7	Burn-in Req'd for Infant Mortality	Purchase baords so they are available	N/A

Table 7: Outcome table for program

In summary, this example illustrates how one semiconductor manufacturing company implements the PMBOK material into their product development process.

3.4 Chapter summary

Having presented a project risk management framework, we will now apply it to new process and product development at Intel. In the next chapter we discuss Intel's existing manufacturing readiness risk assessment system and show how it fits within the PMBOK framework that was discussed in Section 3.2. Then we take an existing framework (manufacturing readiness risk assessment) and modify it for a new purpose (technology development risk assessment).

Chapter 4: Existing and new risk assessment systems

This chapter begins with a description of the Capital Equipment Procurement group's existing manufacturing readiness risk assessment system (within the PMBOK project risk framework) for semiconductor processing tools used to produce microprocessors with the GEN-T process, and how this system is currently employed as a program management methodology in the technology development part of the capital equipment development process. We then show how the PMBOK project risk framework is applied to the group's new needs (to assess risk earlier in the development process) which necessitate a new risk assessment model in the pathfinding phase. The chapter culminates with a discussion of this new technology readiness risk assessment system for the next generation semiconductor processing tools that will be used to produce microprocessors with the P1264 process.

4.1 Project risk management at Intel

Intel's process development cycle has five phases as shown in Figure 6. The pathfinding and technology development phases are the most relevant for this thesis. Intel has a risk assessment process for technology development, but not for pathfinding. This thesis was about adapting the technology development risk assessment to the pathfinding phase. Here are a few terms that will be useful in the thesis:

- **Tools** are the semiconductor processing machines that are purchased from equipment suppliers. In some cases, Intel jointly develops or otherwise works with equipment suppliers to improve these tools.
- **Risk assessment** is evaluating objectively the probability that all of the semiconductor manufacturing tools used to create a new microprocessor product with a new semiconductor processing technology will be up and running on time with acceptable yields, high quality, and the required rate of production output. This takes into account multiple different factors such as performance, cost, safety, support, contracts, and training.

- **Manufacturing readiness risk assessment methodology** refers to the risk assessment that is used during the technology development part of the development cycle to ensure that the tools will be ready for the manufacturing ramp.

- **Technology development risk assessment methodology** refers to the risk assessment that is used during the pathfinding part of the development cycle to ensure that the tools will be ready for the technology development part of the development cycle.
- **Program management** in CEP is managing the development and procurement of the semiconductor processing tools.

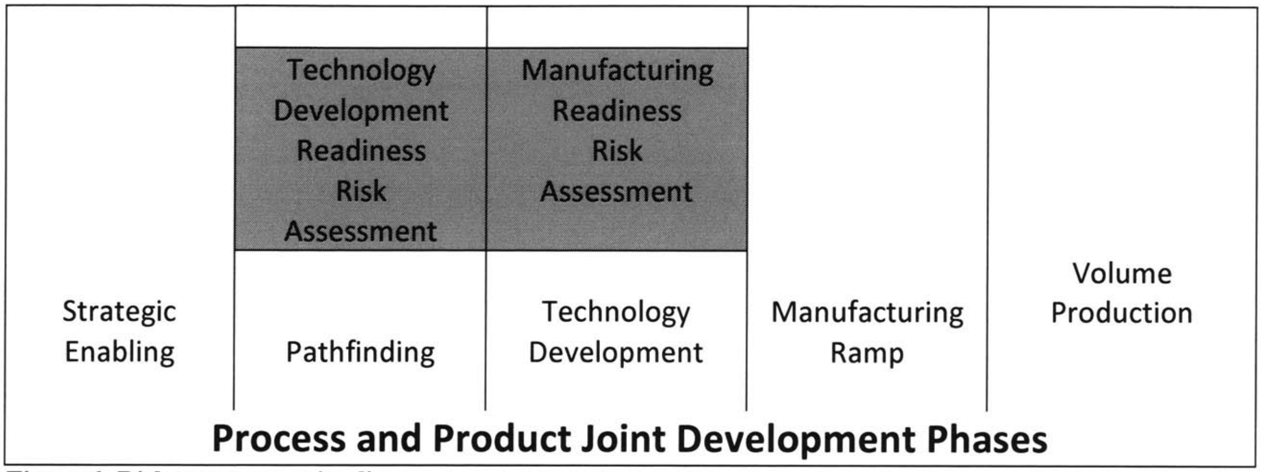

Figure 6: Risk assessment timeline

Intel is in a continual state of process improvement as it attempts to stay one generation ahead of the competition. In this spirit, CEP desires a technology development risk assessment methodology for the procurement and development of the semiconductor processing tools that will be used to produce microprocessor products on the next generation GEN-Q process technology. This enables them to identify and mitigate factors that are likely to impact the joint process and product development very early in the development cycle when the greatest opportunity exists to make an impact on the project.

To address this issue, we developed a model that takes into account the issues that are more relevant earlier in the development cycle (quality, expertise, capacity, contracts and affordability and capability), which will be more fully described later in this thesis.

[54] Prichard, **pp.** 3-23.

The chart in Figure 6 shows the location in the development cycle of the manufacturing readiness risk assessment methodology that is currently in place, and the technology development risk assessment methodology that is newly developed (Figure 6).

In developing this new technology development risk assessment system, we are faced with a tradeoff that all new product and process development project managers are faced with: how to balance 1) the need to address potential issues early in the development cycle when it is possible to rectify problems at a low cost, with 2) the reality that a risk assessment system employs limited resources (such as employees time) in a very tight product cycle. This new system addresses issues early in the development cycle while at the same time minimizing the resource requirements.

4.2 Existing manufacturing readiness risk assessment

The existing manufacturing readiness risk assessment methodology at Intel ensures that all of the semiconductor processing tools will be ready for the manufacturing ramp of a new generation of process technology. The system is shown conceptually in Figure 7 as a set of rings forming a chain.[55] Each ring represents an individual area of risk that might affect the ramp. If there is any area that is not ready, the chain will break and the manufacturing ramp will be delayed. The system is used to maximize the probability that all of the tools and the associated support items will be ready to ramp the technology without any costly delays.

[55] Developed by Athena Murphy at Intel

Figure 7: Manufacturing readiness risk system

Multiple generations of semiconductor processes have been successfully ramped with the manufacturing readiness risk assessment system. Over time, the system has steadily matured as a result of carefully reviewing and improving the risk criteria after each generation of process technology, and users from multiple different departments throughout the company use and trust this stable system. The system has proven itself to be an effective way of minimizing the risks associated with ramping new process generations into manufacturing.

Over the last several processes, the trend has been that the initial risk levels and the final risk levels have been dropping. This is a sign that the technology development process is stabilizing and that there is an opportunity to address issues earlier in the development cycle. This could also be a sign that Intel is undertaking less risky development, but Intel believes that the technology development process is maturing.

4.2.1 Risk management planning background

Risk management planning is the first step in the existing project risk management process. At the start of a new technology development process, a program manager from CEP is assigned to manage the development of the new process technology (GEN-T in this case) within CEP. This manager launches the risk assessment methodology with a review of lessons learned from the previous development which include both process and criteria issues. For example, if the production output capacity did not meet the requirement for the previous generation of technology, the output capacity risk criteria would be modified so that the issue is addressed earlier next time. Changes to the existing risk assessment methodology are documented to incorporate lessons learned and specific program goals for the new project. The initial program goals for the existing methodology were not observed during the internship, so they are not documented. The program goals for the new methodology will be documented in Section 4.4.

4.2.2 Risk criteria

A general description of the individual risk criteria is provided in Table 8. Intel has a set of more detailed descriptions that provide more refined differences between the various risk levels, but they are not included here due to confidentiality. The criteria are continually reviewed by a cross-functional team (including program managers and risk assessors) after each process generation transitions from technology development to manufacturing to improve relevance and increase objectivity. Relevance and objectivity are difficult to quantify, so it is imperative that the reviewers have industry experience and good judgment.[56] The criteria below are representative of what is typically used, but they are not the exact criteria that are being used today.

A universal set of risk categories that are applied to every project at every company does not exist. Instead, risk categories must be customized for individual projects. Intel's existing risk assessment includes technical, quality, and performance categories, but does not include organizational and external categories. Although the organizational and external risk categories are not identified, risks from those sources will be identified by the categories below. For example, an organizational risk such as lack of prioritization for the improvement of output capacity for a specific tool will show up as an output risk if resources are not assigned to improve the output to the required level.

Risk	Description
Output	Will the tool be able to perform to its specified wafer processing run

[56] Pritchard, pp. 34-38.

	rate and availability?
Capacity	Will the tool supplier be able to deliver all of the tools required by the factory on time?
Spares	Will spare tool availability impact factory output or factory resources?
Service	Is the quantity and quality of installation and qualification headcount adequate to meet the requirements for ramp?
Supplier Quality	Are there any supplier quality issues that will affect ramp? The exact definition for supplier quality is determined by the equipment development engineer who supports the tool, and should include at the minimum manufacturing processes, design methodology, change control processes and software quality.
Safety	Are there any open environmental health and safety issues?
Installation / Qualification	Are there any issues that will prevent the installation or qualification of the tool?
Training	Are there any training issues that will impact ramp including training documentation, systems, quality and courses?
Automation	Are there any issues with the tool automation hardware or software that will impact the ramp?
Materials	Are there any material issues that will impact the ramp including specifications, quality, cost, availability, and supplier readiness?
Specification / Contract	Will the specification and contract be closed in time to prevent any impact on the ramp?

Table 8: Manufacturing readiness risk criteria

The overall risk matrix contains risk rankings for each of the tools in each of the risk areas and is owned by the program manager in the capital equipment development group; the individual risk rankings are owned by a variety of different people from different internal organizations. A risk owner is responsible for rating the owned risk and for reducing the risk level if it is elevated. For example, the equipment development engineer within the capital equipment and development group that is responsible for the individual tool owns the output risk for a specific tool. Another example is the service risk which has one representative responsible as the contact for all of the different tools. Although the risk criteria are ultimately owned by the capital equipment development group, the criteria are developed in partnership with the individual owners that are responsible for minimizing the actual risk levels.

4.2.3 Risk matrix

A sample partial risk matrix is shown in Figure 8 with fictitious data. The risk matrix is an overall summary of eleven unique risk areas for each and every tool used in the semiconductor manufacturing process. Each tool is ranked several times per year as high, medium, or low risk at specific times required for the program in each of the risk areas by the appropriate risk owners (e.g., commodity managers and equipment development engineers) who are located in a variety of different departments throughout the company. The three level ranking is the most common ranking technique as shown in Section 3.2.3. The one common qualitative risk analysis technique identified in the literature that is not used at Intel is the differentiation between impact and probability. Instead, Intel combines the two into a simple three level risk summary. A typical modern semiconductor manufacturing fab will have around one hundred unique tools[57] which results in over a thousand unique risk ratings summarized in one location by the risk matrix. Intel likely decided not to track both impact and probability of impact to reduce the amount of data collected and monitored which could lead to potential errors in prioritization.

The purpose of this matrix is to first identify the highest risk areas and then to address them. Additional resources are allocated to the appropriate area as required to minimize the percentage of high-risk items. Once the risk data is input into the risk matrix, it is sorted and analyzed by the project manager to identify patterns or trends. For example, there might be elevated risk levels in one area (e.g., service risk) across all of the tools or there might be elevated risk levels with one supplier. In Figure 8, the supplier quality risk for Supplier C varies for different tools. This often occurs when a large supplier has different divisions that develop groups of tools which results in various levels of supplier quality within a single manufacturer. Patterns or trends are addressed by the appropriate people who are responsible for the different categories or tools and tracked by the project manager with the risk matrix. For example, the data in Figure 8

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[57] Smith

indicates elevated service risk for many of the tools, so a representative from the service group will have to develop a plan to reduce the service risk levels. When no trends are apparent, the individual risk areas are addressed one at a time. The high risk areas are addressed first followed by the medium risk areas, with the objective to have as small a percentage as possible of high risk areas remaining when the transfer from technology development to manufacturing ramp occurs.

Functional Area	Supplier	Tool Description	OUTPUT RISK	CAPACITY RISK	SPARES RISK	SERVICE RISK	SUPPLIER QUALITY RISK	SAFETY RISK	INSTALL / QUAL RISK	TRAINING RISK	AUTOMATION RISK	MATERIALS RISK	SPEC/CONTRACT RISK
F1	A	tool #1	M	L	H	M	L	L	M	H	L	L	L
F1	A	tool #2	M	L	M	M	L	L	M	M	L	L	L
F1	A	tool #3	L	L	M	M	L	L	M	M	L	L	L
F1	A	tool #4	M	L	M	M	L	L	M	M	L	L	L
F1	A	tool #5	M	L	M	M	M	L	M	M	L	L	L
F1	B	tool #6	H	M	H	H	M	M	H	H	L	L	H
F2	C	tool #7	M	L	L	H	M	L	L	M	L	L	L
F2	C	tool #8	H	L	L	H	M	L	L	M	L	L	L
F2	C	tool #9	L	L	L	H	M	M	L	M	L	L	L
F2	C	tool #10	L	L	L	H	M	L	L	M	L	L	L
F2	C	tool #11	H	L	M	H	M	M	M	H	L	L	M
F2	C	tool #12	M	L	M	M	M	L	L	M	L	L	M
F2	C	tool #13	H	L	L	L	M	M	L	M	L	L	L
F2	C	tool #14	L	L	M	L	H	L	L	H	L	L	M
F2	C	tool #15	L	L	L	L	L	L	L	L	L	L	L
F3	D	tool #16	H	L	L	H	M	L	L	M	L	L	H
F3	D	tool #17	L	L	L	L	L	L	L	L	L	L	L
F3	D	tool #18	H	L	L	H	M	L	L	M	M	L	L
F3	E	tool #19	M	M	L	L	M	L	L	M	L	L	L
F3	E	tool #20	M	M	L	L	M	L	L	M	L	L	L

Figure 8: Manufacturing readiness risk matrix

4.2.4 Risk monitoring and control

The first step in the risk monitoring and control process (phase six in the PMBOK project risk framework) is to establish risk levels for all of the individual tools in all twelve categories. This is performed by all of the risk owners. After all of the individual risk levels are determined they are summarized by risk categories, suppliers and individual tools by sorting the spreadsheet data shown in Figure 8.

The second step is a large checkpoint meeting with key stakeholders, where the project risk is reviewed to identify trends and discuss general issues at a high level. This is a key step that enables all of the stakeholders to gain visibility and agree upon the overall risk levels four times per year.

The third step in the risk assessment process is to categorize and reduce the risk levels. This is done on a weekly basis in a small team that invites the owner of a tool that has an elevated risk level in one of the twelve risk criteria to attend the meeting. At this meeting, the tool owners must explain the elevated risk, the plan to reduce the risk, and any help needed to reduce the risk.

The whole process is then repeated on a quarterly basis throughout the process and product development cycle.

4.3 The need for a new technology development risk assessment methodology

In addition to the existing manufacturing readiness risk assessment (that occurs during technology development) there is now a need for a new technology development readiness risk assessment (that occurs during pathfinding). Over the last three generations of process technology, the initial and final manufacturing ramp readiness risk levels have steadily declined as equipment manufacturers have made systematic supply chain improvements. These improvements have created the opportunity to extend the risk assessment process earlier into the development cycle. This project addresses this opportunity by developing a new set of risk criteria that are more important earlier in the process development cycle.

Addressing issues earlier in the development cycle is advantageous for multiple reasons.[58] The ramp speed for new processes is becoming faster and faster with each process generation. This creates increased pressure to ensure that all of the tools are ready

[58] Pritchard

for the ramp. If any single tool creates a delay, huge capital investments will be depreciated without any revenue from new products to offset the costs. There will always be some level of risk in process development required to advance, but the objective is to minimize the amount of overall risk as quickly as possible (the percentage of high risk areas will never be zero, but the high risk areas especially should be minimized). In addition to the depreciation problem, any significant ramp delay will give the competition time to catch up. Intel has been able to maintain a one generation lead in technology, but that can quickly be lost if Intel makes any mistakes in the development of each new generation of process technology or if their competitors take on more risk than they do and leapfrog them.

Intel believes that the current risk criteria allow the risk assessors to make subjective risk level assessments that introduce variability into the risk rankings. This is due in part to the fact that the risk assessors have varying experience and expertise. Since this fact will not change, the new risk criteria have been developed to be as objective as possible.

4.4 New technology development readiness risk assessment

The new technology development readiness risk assessment system was developed for usage as a program management tool to ensure that all of the semiconductor processing tools will be ready to support the development of the next generation of semiconductor process technology. The following is an overview that shows how the six steps in the PMBOK project risk framework apply to the new technology development readiness risk system in this section.

Every project risk management plan is unique for each company and for each project, so the framework will be customized for the pathfinding stage of Intel's future process and product development cycles.

4.4.1 Risk management planning background

Risk management planning is described in phase one of the PMBOK project risk management framework. This is the first step in the project risk management process and is the place where all of the initial planning is accomplished.[59]

The first part of a good plan includes the development of project goals. Several key goals for the project were established: 1) the technology development methodology has to be smaller (fewer implementation resources and fewer risk categories) than the manufacturing readiness one, 2) the technology development methodology criteria ranking system has to be more objective than the manufacturing readiness methodology, and 3) the technology development methodology has to have a similar look and feel to the manufacturing readiness methodology ensuring that users do not have to learn an entirely new system.

In addition to the key goals that were established, the risk management process was outlined showing roles and responsibilities, the methodology, implementation and usage timing, and the interpretation of the three risk level rankings. In the next section the process used to identify the new risk criteria is explained.

4.4.2 Developing and identifying the new risk criteria

Identifying risk criteria is discussed in phase two of the PMBOK project risk management framework. The brainstorming[60] and expert interviewing[61] techniques used to identify the technology development risk criteria shown in Table 9 are discussed in this section.

Risk	Description
Quality	Does the supplier have quality engineering change control, software revision control, and design for manufacturing systems in place?
Expertise	Does the supplier have adequate process engineering, automation engineering, installation, and documentation expertise?
Capacity	Does the supplier have the capacity to deliver the development tools on

[59] *PMBOK® Guide*, pp. 127-130.
[60] Pritchard, pp. 115-120.
[61] Ibid., pp. 57-64.

	time?
Contracts and Affordability	Are contracts closed at a price that meets the program affordability goals?
Capability	Will the tool be able to meet the required performance specification?

Table 9: Technology development risk criteria

There are many potential sources of risk in the process of product development. A list containing over sixty is summarized in *Risk Management Concepts and Guidance.*[62] This type of list is useful in identifying new risk criteria for a completely new product. However, the most useful reference sources for identifying new criteria for previously existing products that are being incrementally modified exist within a company.

The iterative cycle used to identify the new risk criteria at Intel included brainstorming, expert interviewing, consolidation, and management review. The first step in identifying the new risk categories was to determine the requirements for the new risk criteria which are described in Section 4.4.1.

The next step was to evaluate the existing twelve manufacturing readiness risk criteria (described in Section 4.2.2) and determine which ones are still important for the pathfinding part of the development cycle. Some categories were dropped, some were combined into a single category, and some new categories were added to create the initial set of six new categories.

Once the initial potential categories were identified, the next step was to take advantage of knowledge that had been obtained from previous generations of process technology by conducting interviews with experts within the company. Resident experts were interviewed to identify areas that had been problematic in the past or were expected to be problematic in the future. These areas were then compared to the initial six criteria to see if the new criteria would have identified the problematic areas.

After multiple experts were interviewed from all of the relevant internal departments, it was determined that the risk categories had been correctly identified, so they were summarized and shown to a first manager of equipment engineers for approval.

[62] Ibid., pp. 267-273.

The manager made some suggestions and the risk criteria were correspondingly modified taking into account both that feedback and the previous feedback from the experts. Modifying the criteria involved both changing the risk categories and the criteria for ranking the risk as high, medium, or low. Then the criteria were taken to a second manager of commodity managers for review. Similarly this manager had some additional feedback, so the criteria were modified again. This cycle quickly became repetitive since every manager had a different opinion on which risks should be included. After much iteration, the six managers eventually agreed upon the criteria.

The individual risks that resulted from this process are summarized in Table 9 and analyzed in the following section.

4.4.3 Risk criteria analysis

Now that the risk categories have been identified in stage two of the PMBOK project risk management process, we explain the qualitative analysis of the risk criteria. If this was an entirely new project risk management methodology, there are many different methods available for analyzing the risks.[63] However, Intel has an existing risk assessment methodology that has been successfully developed and implemented across the company (e.g., the division that procures discrete parts for circuit board uses a similar methodology), so the new risk analysis methodology must conform to Intel's standard methodology. To conform to the Intel standard methodology, risk rankings will be one of three levels: low, medium, or high. We will now discuss the quality, expertise, capacity, contracts and affordability, and capability risk categories in more detail.

Quality risk

The supplier quality risk category groups together engineering change control, software revision control, and design for manufacturing into a single spreadsheet based questionnaire. The criteria are in the questionnaire format in an attempt to reduce the amount of subjectivity involved in assessing the risk. To perform the risk assessment the user inputs discrete yes or no answers into the questionnaire and then the questionnaire outputs the risk level. The questionnaire shows low risk when there are no gaps (between

[63] Pritchard, pp. 34-38.

the expected quality level and the required quality level) and medium or high risk when there are some gaps. A high risk ranking is differentiated from a medium risk ranking by the lack of a roadmap plan to close the gaps by the technology transfer date. This risk level ranking is determined by an algorithm that assigns a value to each question that is representative of the question's level of importance and then sums up all of the answers to determine a risk level. The importance ratings are initially estimated by the questionnaire developers and will be fine tuned over time with assessment data.

The software revision control is the next section of the quality risk assessment. Many capital equipment suppliers in the past have had multiple different versions of software on different tools including both outdated software as well as unreleased software. This seems like a generic issue, but it has been identified as one of the problem areas on the last several generations of development so it is important to carefully monitor. Additionally the process requires input and approval from the relevant hardware and process experts. Although the software revision control capabilities are difficult to predict objectively, using a controlled process mitigates the quantity of future software problems.

The design for manufacturing section of the supplier quality risk assessment questionnaire attempts to monitor the design for manufacturing capabilities of the equipment suppliers. A customer cannot monitor all of the design for manufacturing capabilities of a supplier, but it can monitor a handful of typical items that experienced personnel have found to be problematic. Some of these items include correctly tagging parts with the appropriate revision and using a comprehensive computer aided design package that incorporates dimensional interference checks. These items have to be monitored and updated as new needs are identified with every generation of development.

The supplier quality risk assessment schedule requires that all quality items be resolved by the time the process is transferred from the pathfinding stage to the technology development stage. This minimizes the probability of any supplier quality issues affecting the technology development.

Expertise risk

The expertise risk category combines supplier process engineering experience, automation engineering experience, installation experience, and documentation into a single spreadsheet-based questionnaire. The questionnaire was developed with an emphasis on the supplier culture and deliverables required to support the technology development process and less emphasis on past performance.

The process engineering experience portion of the supplier expertise risk category consists of six questions that determine if the process engineering experience is adequate. The process engineers must have safety training, experience working with Intel, and several years of experience in their individual area of expertise. In order to make these risk category assessments into yes or no questions, the questions asked, for example, does the process engineer have more than a specific number of years of process experience. This is not exact, however it does enable a risk level comparison between different tools to determine which tool has the higher level although the actual quantifiable risk level might not be known.

The automation engineering experience portion of the supplier expertise risk category contains five questions that are used to determine if the automation engineering experience is adequate to support the technology development phase of the development cycle. The supplier must have the infrastructure to support multiple revisions of machine software and provide rapid on-site support.

The installation experience portion of the supplier expertise risk category contains eight questions that determine if the supplier has the installation experience and resources to support the technology development phase of the development cycle. The installation engineers and technicians must have safety training and installation experience.

The documentation portion of the supplier expertise risk category consists of two yes or no questions that determine if documented procedures exist for troubleshooting known equipment failures and performing required maintenance.

The expertise risk assessment schedule requires that all items should be resolved by the time the process is transferred from the pathfinding stage to the technology development stage. This minimizes the probability of any supplier expertise issues affecting the technology development.

Capacity risk

Tool delivery dates are closely monitored over a six-month period in the pathfinding phase. Small changes in delivery schedule can potentially impact development, so suppliers are required to commit to firm delivery dates and financial penalties if they are missed. The capacity risk ranking is determined by comparing the expected delivery date to the required date.

The dates for all tools are tracked very closely early in the pathfinding phase after exact tool requirements are determined and orders are placed with the tool suppliers. After the tools arrive the risk levels all drop to low and they are no longer tracked.

Cost risk

The cost risk is high if either the cost is not fixed with no roadmap (an action plan describing how to get from one point to another) to close by the hardware freeze date or if the affordability target has not been met. The cost risk is medium risk if the cost is open but has a roadmap to close and meet the affordability target by the hardware freeze date. The cost risk is low if the cost is fixed and it meets the affordability targets.

Capability

The capability risk is high if the supplier's performance specification does not meet Intel's process technology requirements and there is no roadmap to close the gap. The capability risk is medium if the performance specification does not meet the process technology requirements but there is a roadmap in place to close the gap. The capability risk is low if the performance specification meets the process technology requirements.

The development schedule requires that the performance specifications are closed a set amount of time before the first hardware freeze since the specifications must be closed before the contracts can be closed. Writing a specification is much different than actually performing to it, but in the semiconductor capital equipment business long-term relationships have been established between the equipment providers and Intel so there is a trust between the parties that ensures specifications are only agreed upon if they are achievable. During the previous process generation a majority of specifications were closed two months prior to the first hardware freeze. Allowing a buffer prevents the performance specifications from delaying the contract closure. Prior experience shows that about ten percent of the contracts will not be closed by the first hardware freeze. Having the other ninety percent closed allows the organization to focus on closing the remaining ten percent and minimizing the probability of any delays.

4.4.4 Quantitative risk analysis

In the ideal world, a project manager would have access to an accurate description of all risks along with their associated quantified probabilities. This is not possible in a process development that has many unknowns; however it is an ideal goal to strive towards.[64] Two of the risk assessment criteria rankings are quantified with a spreadsheet-based questionnaire. For example, part of one of the supplier expertise risk questionnaires is shown in Figure 9. The risk assessor reads the questions in the criteria column and then provides the appropriate response in the criteria assessment column. After answering all of the questions a risk level is determined for this part of the questionnaire. After answering all of the questions in the other sections of the questionnaire, a total risk level is calculated by combining the individual subsection risk areas.

Installation Experience/Resources		
Section Rating (H/M/L)	Criteria Assessment (Y/N)	Criteria
Safety		
L	Y	1. Has the Engineer/Technician received all required safety training?
	Y	2. Do the Engineer/Technicians receive the same safety training as Field Service Engineers?
Intel Experience		
L	Y	1. Does the Engineer/Technician have prior experience working with Intel?
	Y	2. Is the on site Engineer badged to work at the Intel development fab?
Install Experience		
M	N	1. Has the Engineer/Technician owned tool installations specific to current tool?
	Y	2. Does the Engineer/Technician have installation (suppliers) experience?
	Y	3. Does the Engineer/Technician have factory (suppliers) experience?
Install Resources		
L	Y	1. Is the supplier capable of providing resources to support the installation of tools?
Total Installation ExperienceResources Risk Assessment:		
M		If any category is High Risk, total assessment is High Risk. If any category is Medium Risk, total assessment is Medium Risk.

Figure 9: Partial risk ranking questionnaire

The performance of this new questionnaire technique will be known after the risk monitoring and control phase has been completed since this type of questionnaire has not been previously used for other assessments. Additionally, the specific questions on the new questionnaire need to be tested and fine-tuned throughout the entire pathfinding

[64] Pritchard, pp. 38-41.

phase of the development cycle. Typically new analyses require several iterative cycles to optimize them, so this questionnaire will have to be updated with knowledge obtained by several cycles of assessments.

4.4.5 Risk response planning, monitoring, and control

Risk response planning (PMBOK project risk management phase five) and risk monitoring and control (PMBOK project risk management phase six) are similar to the techniques used in the existing manufacturing readiness risk assessment. It is important to take advantage of the existing organizational process knowledge that has already been developed to prevent the costs associated with learning a new system.[65]

The risk response planning, monitoring, and control will be the same as the ones used for the manufacturing risk assessment process, only on a much smaller scale. First, the risk levels are determined for all of the tools. Second, the risk levels are summarized and discussed in a group meeting with key stakeholders. Third, selected elevated risk items that have been identified with the highest priority are reviewed and reduced on a weekly basis. Then the whole process repeats itself on a quarterly basis.

4.5 Risk assessment example

A fictitious scenario is developed in this section to illustrate the risk assessment process for a single tool. Although the process appears relatively straightforward, it is much more complicated and requires detailed documentation when the project manager is managing a hundred tools at one time.

Week 0: Initial risk assessment

The initial risk assessment is initiated by the program manager who establishes the risk criteria by working with the experts on the various tools sets to determine the appropriate areas and level of risk represented by each tool. The areas common to semiconductor equipment are performance to specification, on-time delivery, capacity, and cost. These can be mapped to the risk areas outlined in section 4.4.

65 Pritchard, pp. 25-48.

Week 2: First weekly risk reduction meeting

After the project manager reviews all of the risk data, several tool owners whose tools have high risk rankings are invited to the first weekly risk reduction meeting. For this meeting, the commodity manager prepares a one sheet presentation showing why the tool is ranked high risk, the plan to lower the risk, and requests for help needed. After discussing potential opportunities to lower cost risks for a tool, it is determined that the commodity manager should contact the supplier and ask for suggestions.

Week 3: Negotiations with supplier

After contacting the supplier identifies that the high cost is caused by tight specifications that require costly and time consuming manufacturing processes and suggests that if the specifications are loosened the costs can be lowered. The commodity manager works with the equipment development engineer to determine that the feasibility of the specification change proposed by the supplier is acceptable. If the wider specification still meet the process and product requirements, then the specifications are adjusted and the risk profile is reduced.

Week 4: Third weekly risk reduction meeting

Having addressed all high risk tools issue, the risk reduction meeting focuses on medium risk items. The equipment development engineer responsible for a tool is invited to the meeting to explain the medium capability risk rating. If additional resources are needed to future investigate and resolve medium risk items, then the priorities are set to allocate the appropriate resources to meet the overall program goals.

Week 5: Fourth weekly risk reduction meeting

The tool engineer explains that the tool's performance shortfalls are known by the supplier, with internal resources also addressing the performance gap. Since all of the appropriate people are engaged in solving the problem, it is determined that no additional actions are required at this point in time by MES and the risk level remains at medium risk.

Final week: Project transfer from pathfinding to technology development

At this point the technology development risk assessment ends and the manufacturing readiness risk assessment begins. The status of all of the risks is documented and transferred to the new team. Each tool has a risk profile assigned based on the results of the risk reduction activities over the past weeks. A transistion document is put in place to ensure that the new team will continue to monitor the risk until it is resolved.

One important part of this transition is the documentation of lessons learned, so that the process will be improved for the next generation of technology development.

4.5 Chapter summary

In this chapter the PMBOK project risk management framework was first applied to the existing manufacturing readiness risk system to explain the existing system. Then, the framework was used to develop a new technology development risk system. In the next chapter, we critically analyze the project risk assessment methodologies at Intel, in an effort to suggest additional future improvements.

Chapter 5: Critical analysis of project risk management

This chapter critically analyzes the project risk assessment methodology at Intel that has been developed and used to successfully manage the introduction of multiple new generations of process technology. Other industries and literature show variations in project risk management methodologies that Intel can learn from. Potentially, Intel could change the way that they identify and rank risks. Intel should study the benefits obtained and costs required by the new technology development risk assessment to ensure that it achieves the expected results at the expected cost. One additional opportunity for improvement to the current Intel process is to utilize a new software tool that can better manage data collection and analysis. Although the existing system works, it should continually be reevaluated to determine if it can be improved.

5.1 Risk identification

It is important to conduct project closure reviews at the conclusion of projects to increase an organization's knowledge base. Although the importance of these reviews is well known, they are often executed in a cursory fashion resulting in the loss of knowledge.[66] One important part of these reviews for project risk management is the reevaluation of the existing risk criteria. Risk categories should either be dropped, if they were not useful, or new ones should be added if there is an opportunity to identify and address a new risk area.

Pritchard (2001) identifies and explains twelve different techniques to identify risk areas.[67] Of these techniques, the most commonly used ones are expert interviewing and brainstorming, which Intel currently uses. One technique that is not currently in use is the comparison of risk categories with external sources. A list of 60 possible risk sources used to identify new risk categories is available from multiple sources and included in Appendix A.[68] The advantage of using an external list is that it can potentially identify new risk areas that had not been considered by people within the company.

[66] Royer, p. 8.
[67] Pritchard, p. 53.
[68] Ibid, pp. 267-274.

Royer (2000) shows that much of the knowledge obtained from project risk management often stays with the project manager.[69] Since there is often not enough time to adequately conduct the end of project review, it is important that project managers take it upon themselves to document the lessons learned from a project risk management program. These documented lessons learned can be combined to create a project risk checklist to aid future program managers that do not have significant experience. An inexperienced program manager can use these checklists during a brainstorming session to identify new risk categories for a new project. This is one technique that will lower the loss of project knowledge associated with a person moving to different positions, which occurs regularly at Intel. Capturing information from various projects in a central place should be one part of the CEP program management function, if it is not already.

Project risk management has been successfully used at Intel for the development of multiple generations of process technology. Intel conducts post project reviews, but the content of these reviews was not observed during the internship. These reviews provide an opportunity for Intel to reevaluate the risk areas if they do not do so already. It is important that in addition to identifying new risk categories, the existing risk categories must be evaluated to determine if they are still appropriate. There is a cost associated with monitoring each category, so it is important to eliminate the ones that have proven to not be useful over the last several generations of products.

In addition to the risk identification processes that Intel currently uses, they should evaluate the external risk lists and the documentation of program management lessons learned described above. It is not guaranteed that these techniques will identify additional risk areas every time they are implemented. However, it is possible that they will bring up a risk area that had previously not been considered that could have significant cost and scheduling savings on the next generation of process technology. This potential for significant cost savings warrants the small cost associated with the new risk identification exercise at the end of each project.

[69] Royer, pp. 7-13.

5.2 Rank both risk probability and impact

The current risk ranking methodology at Intel only ranks the probability of the risk occurring and not the impact if the risk occurs. One common practice implemented by other companies is to include a ranking for both probability of occurrence and impact.[70] This provides more information to better prioritize the risks for resolution. For instance, a risk that has a medium probability of occurring and a high impact if it occurs should be addressed before a risk with a high probability of occurring but only a low impact if it occurs. Although implementing this expanded ranking process will provide more information that can be used to make better informed program management decisions, Intel might not want to implement it since it requires more work and differs from Intel's standard risk methodology.

The additional work includes rewriting the questionnaires, a small amount of time to make the more detailed assessments, and then more time to manage the additional information. The questionnaires have to be modified to define precisely the probability of the risk item occurring and the impact. The existing questionnaires have been fine tuned over multiple generations, so making changes is disruptive and requires several additional generations before they are accurate. After the new questionnaires are finalized, it probably will not take much more time for the individuals providing the inputs to the risk assessment matrix to provide two ratings for each item, but the risk matrix prioritization and management process will take slightly more work. Currently, there are around a thousand individual risk rankings that must be managed. Monitoring both probability and impact will double the amount of information that the program manager is required to manage. Managing the data in the existing system is time consuming, so managing additional data will be more time consuming. Although all of the data is in a single spreadsheet, additional work will be required to sort and identify trends in the data before it can be prioritized for action. Intel must determine if this additional amount of work is less than the benefits that will be obtained by having the additional information available to better prioritize the risks.

The second potential issue with ranking both probability and impact is that it differs from the standard risk methodology that currently exists across Intel. Other

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[70] Thompson, pp. 50-53.

departments such as the computer motherboard department currently use a similar methodology to monitor the risk for all of the discrete components that are mounted on motherboards. It is advantageous for a company to keep processes consistent across departments. Having a company process that is slightly suboptimal for a given department is acceptable, but it is not acceptable if it is significantly suboptimal. The MES group should reevaluate the current company-wide risk assessment methodology to ensure that it is the best policy for the needs within MES and change it if it is not optimal.

Before any changes are made to the company-wide methodology, it is important to confirm that the changes are beneficial. This can be done with the current assessment by taking the current list of risk items, and generating probability and impact assessments. Then, they could see if the prioritization would be different to test weather or not any different decisions would be made if they had both probability and impact data. This is one method to determine if the current system is working to identify risk areas as is it should.

5.3 Institute risk assessment as early as cost-effective in the development cycle

Incremental changes to existing processes at Intel must always be evaluated after implementation to ensure that they are both beneficial and cost-effective. For example, potential risk areas should be addressed as early as cost-effectively possible within the product development cycle. In most product development processes there is more opportunity to influence the outcome earlier in the development cycle. As a project comes to conclusion, the opportunities to make changes (at all or at a cost-effective price) are significantly reduced.71 This effect is amplified greatly in a process that is as complex and precise as semiconductor manufacturing where even the smallest change can have major negative impact.

Addressing issues early does have some associated costs, such as the cost of employee time to make risk assessments. This is a delicate tradeoff that will depend on: a) how risk adverse the company is; b) does the company (or people with experience in the specific type of product that is being developed) believe that risk assessment models will be beneficial; and c) does the company have experience in the manufacturing process

7J Wideman, pp. II1-7.

or project in general (for example, a start-up may not have the financial resources to have employees dedicated to risk solely and also may be going through a particular process for the first time, so it may not know all the significant risk factors). Management must balance these factors to determine if the probability that the additional resources required will provide a return greater than the cost associated with utilizing the resources.

At Intel, management has suggested that an additional risk assessment should be performed during the pathfinding part of the development cycle. After implementation of the new risk assessment methodology, management should reevaluate the decision to have an additional risk assessment performed to determine if the benefits of the new system are greater than the implementation costs.

5.4 Implementation with existing IT systems

The risk assessment matrixes are currently implemented with a standard spreadsheet program. The problem with this implementation is that its usage is time consuming and its data accuracy is poor, which leads to additional time wasted investigating the inaccurate data. There are two different, but equally undesirable, ways to use a spreadsheet with a large group of users that need to input data. The first way is to put the spreadsheet on a shared drive and let everyone update the data that they are responsible for. This is problematic because there is no update history and there is no accountability. The second way is to have one person responsible for all of the data entry. This method has slightly improved accountability and data accuracy, but at a cost of wasted resources since every update is done through a third party instead of directly. In addition to the time requirements for the data entry person, there is a significant amount of time required from each of the risk ranking owners who must continually rank, confirm, explain, and update the risk rankings. This inefficient use of time was confirmed by conversations with multiple people within CEP during the internship.

A better solution may be to use new technology to enable users in an organization to easily create, manage, and build their own collaborative Web sites and make them available throughout the organization. Such capability is available in web-based knowledge sharing applications. This is being recommended since one of these applications is currently being rolled out within Intel for several different applications, so users will not have to learn how to use a new software product solely for the risk assessment effort since they are using it for other projects.

Replacing the existing spreadsheet-based readiness process with a web-based application provides the following benefits that are not available in the existing spreadsheet program:

- Easy to track changes and the specific users that made them
- Permission management
- Easily created web based forms linked to databases
- Easy to use surveys with user friendly formats such as radio buttons
- Forty people can fill out a survey at the same time (spreadsheets would require forty people to check out the document and then return it to the owner or the shared drive)
- Change alerts for user defined database updates
- Weekly summaries
- Data directly linked to Office 2004 products and provides real time updates
- Survey response can be merged with other data sources and can be linked together

The implementation requires that the existing spreadsheet-based database be transferred to a web-based database with one additional field. The new field would be used to identify the group of users that have access to a given section of the database. The web-based knowledge sharing application has the capability to set permissions based upon who is identified in the new field. For example, one new field would be the commodity managers responsible for the tool, which would allow them to update the cells that they are responsible for and prevent other people from modifying their entries.

A concern in implementation is resistance to having to learn another new tool. However, as users become familiar with the web-based knowledge sharing application (either through risk assessment usage or through other projects), recognition will show the new application is similar to other common products and requires a modest amount of time to learn how to use. A second concern is that the person setting up the survey will need to have more in-depth knowledge to correctly set up the database. However, the users will be able to immediately use the new database with relatively little training.

There is some risk involved with abruptly dropping the existing spreadsheet process and switching to a web-based application. A preferred transition method is to conduct a pilot on a small section of the risk assessment in parallel with the existing spreadsheet. Upon the successful completion of the pilot the entire risk assessment can be switched over with much lower uncertainty in the new tool.

5.5 Chapter summary

Project risk management is an important part of the program management process. Applying the recommendations discussed in this chapter will increase the effectiveness of the project risk management implementation. Project cost modeling is another useful program management tool that we discuss in the next chapter.

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Chapter 6: Literature review of cost management systems

This chapter provides an overview of the evolution of cost management systems and then describes some of the modern ones that are used today to successfully manage company costs. The material for the history, evolution, and activity based costing part of the material in this chapter is taken from two sources: *The Design of Cost Management Systems,* written by Cooper and Kaplan and *Cost and Effect: Using Integrated Cost Systems to Drive Profitability and Performance,* written by Cooper and Kaplan.[72] Cooper and Kaplan, two of today's most referred to writers in cost management, provide an excellent overview of modern cost management systems in these books.

After the cost models and their use are reviewed historically, the second half of this chapter explores the key ideas of and recent literature on target costing and total cost of ownership, as these two methodologies are heavily used at Intel (as discussed in the next chapter). Together, they enable the effective cost management of product and process development.

6.1 History and primary functions of cost management systems

There were no significant changes in the practice of cost accounting from the early 1900s until the 1980s when Activity Based Costing (ABC) emerged as a way to more accurately track costs. ABC systems are costs accounting systems that tie actual costs to the direct performance and value of activities. After ABC, a second significant change has been the emergence of Activity Based Management (ABM) which is the operational and strategic infrastructure accompanying ABC. ABM is significant because when it is combined with cost management techniques such as target costing, ABM enables new ways to reduce costs both across the value chain and over the life of a product. These developments from 1980 forward have led to a change in the role of finance from a passive reporter of history to a proactive influencer of the future.

Cost and performance measurement systems have become embedded in the formulation and implementation of strategies and operational improvements. There are three primary functions of cost management systems:[73]

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[72] Cooper
[73] Cooper, p. 1-7.

1. Measure cost of goods sold and value inventory for financial reporting
2. Estimate costs of activities, products, services, and customers
3. Provide economic feedback to employees and operators about process efficiency

6.2 The four phases of cost management system evolution

The evolution of cost management systems is described in the following four stages:

- Stage I systems are rudimentary systems that do not perform any of the three primary functions described above very well.
- Stage II cost management systems measure costs of goods sold and value inventory for the financial reporting function, but are not useful for the other two primary functions of cost management systems. Historically only direct labor and direct material costs were measured and controlled, and overhead or indirect costs were allocated on the basis of the direct labor and materials content of a product. This was acceptable because direct costs were a large proportion of the cost of a product, and thus the most important to control. Today, indirect costs are a larger proportion of product cost, and must be better understood.
- Stage III systems comprise multiple standalone systems that each perform one of the three primary functions well. Activity based costing is a type of stage III cost management system that enables better strategic decision-making and prioritization for process improvement activities than traditional cost systems. Traditional cost systems, for example, emphasize variances against standards which promotes a controlling, not a learning, view, as variances are not easily understood by front line employees and do not directly encourage continuous improvement activities. Stage III systems provide performance measurement feedback to employees on the cost, efficiency, quality, and timeliness of the business process being performed and allow employees to see the cost and revenue impact of their actions and local team improvement activities.
- Stage IV cost management systems integrate multiple stage III systems into an Enterprise Resource Planning (ERP) system to perform all three of the primary cost management system functions well. ERP systems coordinate all of the major business

functions including purchasing, manufacturing, marketing, sales, logistics, human resources, and accounting.

6.3 Activity based costing

Activity Based Costing (ABC) is an example of a stage III system that is used to actively manage projects in modern companies. It is important to understand the benefits achieved with modern cost systems that go beyond the traditional cost systems that reported cost information after a product was designed and manufactured. This understanding of ABC is important to enlighten the reader on the cost system at Intel (which we will discuss in Chapter 7), because Intel's system proactively manages costs during the process development phase of the product life cycle.

As background to stage III systems (to see what stage III systems fix) we need to examine stage II systems. Stage II systems assign indirect and support costs to products with volume based cost drivers, such as direct labor, machine hours, and material dollars. This leads to distortion because indirect and support costs are not always proportional to volume based cost drivers. Stage III systems, such as ABC, avoid such distortions by assigning costs through a logical and systematic set of three procedures:

1. Identify the activities performed by the organization's resources
2. Determine the cost of performing these organizational activities and business processes
3. Determine how much of the output of each activity is required for each of the organization's products, services, and/or customers

A properly constructed ABC model provides an economic model or map of the organization's expenses, based on organizational activities. As a simple example, suppose Intel's high volume factory makes 100,000 microprocessor chips and a second Intel factory that makes 100,000 chips of all sizes, types, and colors. The first factory has equivalent costs for every chip produced, while the second factory has much different costs. For example, if the second factory produces 100 red chips and 99,900 blue chips, the costs associated with changing over production to make the red chips make the cost per chip much higher for the red chips compared to the blue chips. As Intel moves from a largely high volume low mix environment to on with higher mix, it will have to change its cost systems accordingly. ABC systems have the greatest impact when significant diversity exists in the quantity and types of products being produced. More precisely, it has greater impact when significant diversity exists in the consumption of the organization's resources by those products or services. ABC can also be applied to understanding the costs of customers, suppliers and distribution channels. The primary benefits of ABC include:

- **Better understanding of consumption of major resources:** An ABC system allows a company to show exactly what part of a resource is used to produce a product and what part of a resource is not used. This knowledge can be used to make better decisions regarding committed and flexible resources.
- **Better understanding of product line profitability:** The product mix can be changed to focus on the profitable products and drop the unprofitable ones. This application of ABC influences product development and supplier relationship decisions. Without ABC it is easy for an organization to develop a large variety of products without understanding that a majority of the profits come from only a small percentage of the total product offerings. This is not always the case because often customers want a full line of products and there may be sunk costs from prior development projects. However, the point is that with ABC a company has the ability to make more informed decisions.
- **Better understanding of costs of dealing with individual customers and distribution channels:** Extending ABC to include customers and distribution channels enables a company to expand its business with highly profitable customers and/or channels, and discount products to gain business with lower total cost customers. Unprofitable customers or distribution channels can be conceded to the competition and high profit customers can be captured from the competition.
- **Better understanding of costs associated with specific suppliers:** Supplier relationships have traditionally been adversarial with the final purchase decision being determined primarily by the lowest price. Now, activity based costing systems enable decisions to be made based upon the lowest total cost of ownership. Besides the cost of the product, the cost to negotiate, contract, receive, inspect, scrap, delay

production, and expedite material can all be understood together to determine the total cost of ownership associated with working with a specific supplier.

- **Better understanding of costs for product design:** It is estimated that 80% or more of manufacturing costs are determined during the product development phase.[74] Stage II cost systems focus only on direct material and labor without any information on costs of procurement, unique versus common parts, new versus existing vendors, or simple versus complex production processes. Stage III cost systems, in contrast, provide product designers the information needed to make design decisions that lower the total manufacturing costs of new products. For example, if the goal is to reduce part costs, then the designer might naively reduce the cost of each and every individual part, focusing on direct materials costs. This does not take into consideration the additional overhead costs associated with the total quantity of parts and vendors to be managed.

It is important to note that the goal for an ABC system is not to provide the most accurate costs; rather it is to influence a desired behavior. The resource cost associated with accurately measuring costs must be less than the cost benefit that the desired behavior provides. For example, measuring costs to 0.01% accuracy may provide no additional benefit compared to measuring costs to 1% accuracy for the purpose of influencing behavior. Another issue that must be addressed is to determine what level of detail should be included in the development of the ABC system. For example, procurement overhead can be broken down and associated with the number of different part numbers, total number of parts managed, and/or number of vendors managed. This is a manager's decision based on ease of use and resource costs.

6.4 Target costing for product development

Target costing is another approach to managing cost, particularly in the product development process. The name target costing implies that it is a simple technique of setting cost targets; however, target costing is a much more complex process that is used to motivate employees from various functional areas to develop products that will be affordable in the market place. In target costing systems, cost becomes an input to the

[74] Michaels.

product development process instead of an output after the development is completed. In *Best Practices in Target Costing,* Swenson identifies the following six key principles of target costing:[75]

- **Price-led costing**: Market prices are used to determine allowable costs. Target costs are calculated using the following formula:

  target cost = market price – required profit margin

- **Focus on customers**: Customer requirements for quality, cost, and time are simultaneously incorporated in process and product decisions and guide cost analysis. The value (to customers) of any features and functionality built into the product must be greater than the cost of providing those features and functionality.
- **Focus on design**: Cost control is emphasized at the product and process design stage. Therefore, engineering changes must occur before production begins, resulting in lower costs and reduced time to market for new products.
- **Cross-functional involvement**: Cross-functional product and process teams are responsible for the entire product from initial concept through final production.
- **Value-chain improvement**: All members of the value chain (e.g., suppliers, distributors, service providers, and customers) are included in the target costing process.
- **Total cost of ownership**: Total life-cycle costs are minimized for both the producer and the customer. Total cost of ownership costs includes purchase price, operating costs, maintenance, and distribution costs.

The target costing process can be broken down into the following four steps:[76]

1. **Market driven costing:** The target selling price (perceived value of the product in the eyes of the customer) is identified.
2. **Product level target costing:** The expected cost of the product under development product establishes a baseline cost, which is compared to the allowable cost to identify a cost reduction target. Employees use techniques such as value engineering

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[75] Swenson, pp. 12-13.
[76] Kaplan, pp. 217-227.

and design for manufacturing and assembly to reduce costs to achieve the allowable cost target.

3. **Component level target costing:** The product level target established in step two is broken down into individual cost targets for every part and process that makes up the product cost. During this step, suppliers are often brought into the development company to help design parts with lower costs that meet the desired individual component target costs.
4. **Chained target costing:** The entire supply chain is evaluated for overall global efficiency.

Intel's cost model, developed in Chapter 7, takes the market driven cost of a new chip as an input and a starting point. From this market cost, the product level target cost for the semiconductor capital equipment required to make the part is determined. This product level target cost (of the equipment) is compared to the existing baseline cost to determine the magnitude of the cost reduction that must be achieved for the equipment, and thus the product, to be affordable. Then, the baseline and target costs are broken down from total costs to the individual component level costs, which in this case set a target cost for every piece of semiconductor manufacturing equipment that is used to produce the product. The employees within CEP take the individual equipment costs and target equipment costs and work with the suppliers to complete the last phase of the process, chained target costing.

6.5 Total cost of ownership

In Section 6.4, we discussed how the total cost of ownership is a key principle for target costing. We expand upon this principle in this section, since it is important for the cost model developed at Intel. Total cost of ownership is the sum of the direct and indirect costs associated with the purchase, operation, and disposal of a piece of capital equipment. Historically, purchase decisions have been based on initial purchase and installation costs. However, purchase costs do not consider the effect of equipment reliability, utilization, and yield over the life of the system. These factors often have a greater influence on the total cost of ownership of the equipment than the initial purchase price alone.

In *Long Term Cost of Ownership: Beyond Purchase Price* by Ross Carnes,[77] a total cost of ownership model is developed for a semiconductor process. The model includes fixed costs, variable costs, utilization factors, throughput rate, and yield to arrive at the total cost of ownership. Fixed costs include purchase, installation, and facilities costs that are amortized over the life of the equipment. Variable costs include all costs incurred during the operation of the equipment such as floor space, overhead, utilities, repair, material, and labor. An example is constructed that compares two machines and shows that the more expensive machine (based on purchase price) can have a lower total cost of ownership if it is higher performing or cheaper to operate. It is important that these types of costs are all included in the cost model developed in the next chapter.

6.6 Chapter summary

Cost management systems have evolved over time. An important change has been the development of activity based cost systems to manage projects in addition to reporting costs. A further evolutionary step has been target costing to manage costs during product development. Finally, the total cost of ownership methodology is an important tool to manage entire lifecycle costs instead of purchase costs alone. In the next chapter, the cost model methodologies described in this chapter are applied to the development of a new cost management system at Intel.

[77] Carnes, pp. 39-43.

Chapter 7: Target Cost-Based Modeling at Intel

The chapter discusses cost models at Intel where many costs models exist across the entire organization for different purposes. Intel, as a corporation, evaluates and tracks all elements comprising the total cost of a wafer. The Capital Equipment Procurement group, however, only interacts with the subset of total costs that they have control over in the course of managing interactions with equipment suppliers. We will describe the difference between the existing cost model used for the GEN-T process and the newly developed cost model used for the GEN-Q process. Then we will discuss the target costing approach that consists of setting the capital equipment target cost, establishing the baseline cost, and then tracking cost projects.

7.1 Expected wafer cost models at Intel

Large complex corporations, like Intel, typically have multiple cost models, each customized for specific areas, located throughout the company.[78] Multiple models are required so that each area has control over the model that is used in its area. For example, CEP needs to control exactly what is included and when updates are made for the cost model for its area. In this section, we first discuss a model that is used to control the entire cost of a semiconductor wafer (Section 7.1.1). Then, we discuss cost models that are used within CEP (Section 7.1.2) to control the portion of the total wafer cost that CEP is responsible for.

7.1.1 Cost models for the finance group responsible for total wafer cost

The finance group responsible for the total wafer cost is responsible for accurately determining the expected cost per wafer during process and product development. Since parts of the wafer cost are determined even before the completion of the design of the process technology (two years before a chip goes into production), costs have to be controlled early in the process when the opportunity to control them still exists.

78 Cooper, pp. 136-140.

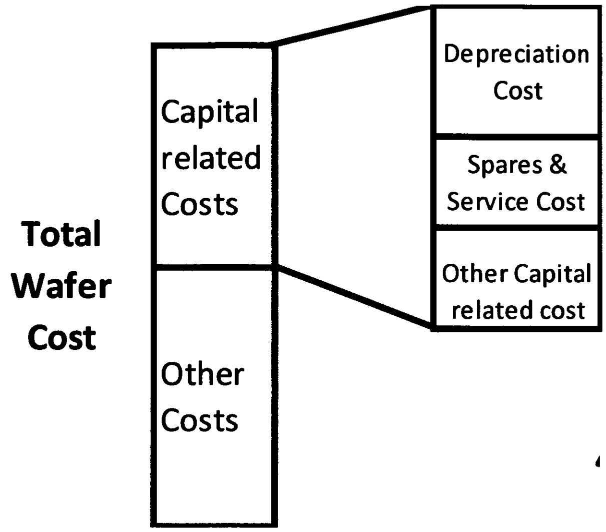
Capital Expenditure	$600.00
Direct Cost	
Spares & Service	$100.00
Labor	$80.00
Raw Material	$80.00
Indirect Cost	
Depreciation	$100.00
Overhead Cost	$10.00
Utilities and Training	$20.00
Others	$10.00
Total Dollars per wafer	$1,000.00

Modified / recommended Table-10

Table 10 shows an example of the capital, direct, and indirect costs that together make the total expected wafer cost. The exact cost categories and values that Intel uses are not disclosed since they are both Intel confidential.

7.1.2 Cost models for the Capital Equipment Procurement group

The Capital Equipment Procurement group at Intel has the challenge of influencing the affordability of a new product by controlling the cost of the capital equipment that contributes to the new product cost. This cost control is accomplished during the development stage of the product cycle before the process used to produce the product is frozen. The cost model used to control this process calculates the partial wafer cost that CEP controls, not the entire wafer cost as depicted in Figure 10. This figure is not an accurate representation of all of the costs of a wafer; instead, it illustrates the concept that CEP only controls some of the wafer costs.



Modified/ recommended Figure-10

Figure 10: CEP influenced wafer costs

CEP controls the costs associated with specifying performance requirements, purchasing, installing, and maintaining the equipment used in semiconductor production. They are not responsible for the other costs associated with actually producing the chips. However, they must be aware of the total cost of ownership associated with the capital equipment to ensure global cost control instead of local cost control. For example, consider the situation that might occur when CEP is considering the purchase of one of two different semiconductor processing tools which each have the capability to perform the same task. One might have a lower initial cost, but have a higher total cost of ownership. CEP must work with the suppliers to address issues that contribute to the total cost of ownership before the final equipment specification is approved and the equipment is purchased.

Capital Equipment Procurement group cost model needs

The Capital Equipment Procurement group has particular needs from a cost model. As previously mentioned, CEP does not need an accurate cost of the entire wafer. CEP does need the model to support organization, project management, and cost management objectives. In the case of organization objectives, the cost model should show the CEP group's contribution to the wafer cost reduction process to the larger organization, and requires localized control of cost model usage. To support project management objectives, the cost model must have the ability to influence product affordability during the process development phase of the development cycle. In addition, the model should provide cost reduction status showing the initial expected cost, status of cost today, and target cost for the capital equipment portion of the total wafer cost. Finally, to enable the management of cost objectives, the cost model must meet several goals: it must show the cost for the portion of the entire wafer that the CEP group is responsible for controlling; it must aid in understanding of how supplier negotiations affect wafer cost as well as of how semiconductor processing tool productivity changes affect wafer cost; and it must show wafer cost broken down to the individual tool level (the total wafer cost only shows total capital cost, not the cost of individual tools).

7.2 Different cost model requirements for the existing and new models

Table 11 summarizes the model requirements that are different between the existing GEN-T cost model and the new GEN-Q cost model that is developed in this thesis. After describing these model requirements, the section ends with a summary of the feedback received from users of the existing GEN-T model (Section 7.2.6).

	Existing cost model	**New cost model**
Process name	GEN-T	GEN-Q
Percentage of Intel business	Majority	Minority
Percentage of CEP workforce	Majority	Minority
Process equipment	New 300 mm	Reused 200 mm when
Manufacturing product environment	LMHV	HMLV

Baseline cost	Set once	Reset after forecast changes
Production volume	Normalized	Forecasted

Table 11: Different requirements for the existing and new cost models

7.2.1 Allocation of personnel across process technologies

Existing GEN-T cost model requirement

In the Capital Equipment Procurement group, the number of resource personnel assigned to support the development of a new semiconductor manufacturing process is allocated to be a cost effective balance associated with the anticipated deployment of the technology. The GEN-T process that will be used to produce a significant portion of future revenue and therefore a correspondingly large percentage of CEP's employees are assigned to support it. All of these resources are used to analyze the tool set that will be used in the GEN-T process. The group must still prioritize projects since there are not enough resources to do everything.

New GEN-Q cost model requirement

The GEN-Q process is expected to generate a significantly smaller percentage of future revenue for the company. Therefore, there is a correspondingly smaller group of people that are assigned within CEP to support the GEN-Q development. There are only enough resources available to focus on the cost reduction projects that will have the largest expected returns.

7.2.2 Type of semiconductor process equipment

Existing GEN-T cost model requirement

GEN-T is a process technology that requires the development and procurement of predominantly new equipment. Therefore, the GEN-T cost model only includes the new equipment costs.

New GEN-Q cost model requirement

In contrast, GEN-Q is a process technology that will use a significant amount of previously purchased used equipment. The GEN-Q cost model has to include a variety of models for all equipment types with newer processing capabilities.

7.2.3 Characterization of manufacturing process

The GEN-T process is characterized as Low-Mix High-Volume (LMHV) since it will be used to produce products in high volume. The GEN-Q process is characterized as High-Mix Low-Volume (HMLV) since it will be used in an environment that will be producing products on multiple different processes. The manufacturing process environment influences the requirements for a cost model: the HMLV process requires a cost model that is significantly more flexible than the one required for LMHV.

7.2.4 Timeline requirements to set the baseline semiconductor manufacturing cost

The GEN-T and GEN-Q processes also differ in the timeline used to establish manufacturing costs. The existing GEN-T cost model sets a manufacturing cost earlier in the development cycle due to the LMHV profile of the process. However, the new GEN-Q cost model requires the manufacturing cost to be set later in the development and production cycle for the tools set used on a HMLV process.

7.2.5 Tool quantities for the expected production volume

Existing GEN-T cost model

The existing GEN-T cost model, which is common across the semiconductor industry uses a normalized greenfield methodology to determine the quantity of each tool type required to populate a new factory (built from the ground up) that has the capacity to process a normalized quantity of wafers. This facilitates the cost comparison of multiple different generations of semiconductor process technology that is independent from the actual production volume capacity at specific manufacturing facilities.

New GEN-Q cost model

The normalized tool quantity methodology used in GEN-T is not suitable for the GEN-Q process, which will have a diversified set of tools. The new model will use actual expected tool quantities that are dependent upon the expected production volume. The production volumes for the GEN-Q process along with the production volumes for multiple other processes are all taken into account in determining which tools will be available for reuse in production of the GEN-Q process. This prevents the cost comparison of multiple processes generations over time that the normalized model is capable of performing, but it provides a more accurate estimate of expected costs.

7.2.6 Feedback from users of the existing GEN-T model

The users of the existing GEN-T model were interviewed to determine potential improvements. The users fell into two distinct groups. One group believes that the existing model is too simple. They would like additional capabilities such as the ability to evaluate multiple qualified suppliers, more robustness, sensitivity analysis, and real time projected cost updates upon changes in various databases controlled by multiple different groups.

The second group believes that the existing models are too complex. They want simpler models with clear, easy to use interfaces that can be run by all users with expert help. The second group is concerned that the models have become so complex with interconnections to multiple different data sources, which makes it difficult to interpret the outputs. The existing models show cost changes from one day to the next, but the user does not the source of the change.

For example, if a commodity manager negotiates a lower price, she expects the wafer cost to decrease. Then when the cost model is updated, and it shows that the cost per wafer has increased there is no way for the manager to track impact of the lower price or the cause for the change.

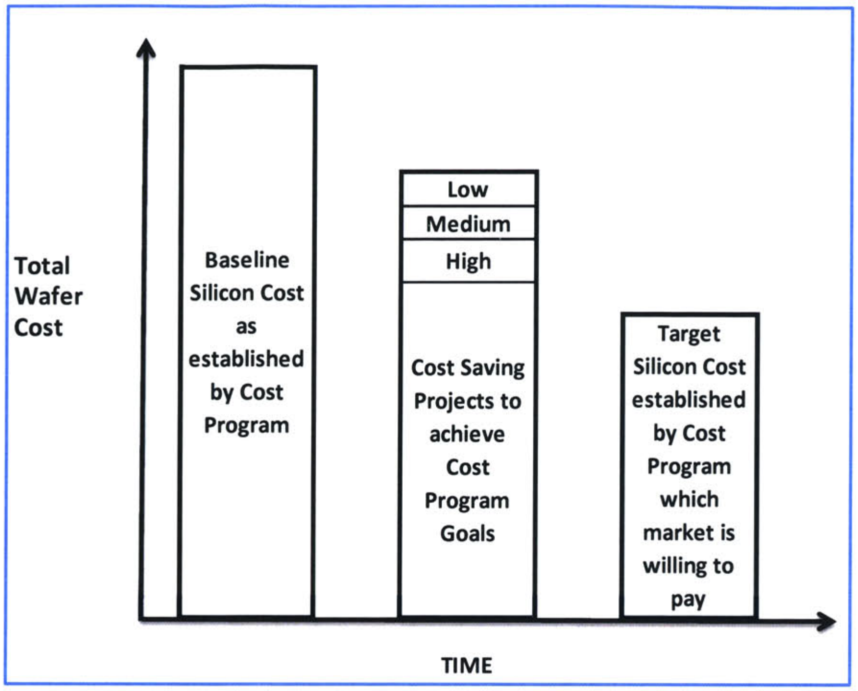
One potential solution that addresses both these points of view is to develop a more complex model that appears less complex. A model could be developed that would accurately calculate costs continuously and then display detailed cost changes from the previous cost summary clearly through a user interface. However, the accurate cost calculations that are updated continuously will appear as noise that will mask the actual wafer cost reduction contributions from people within MES.

An alternative approach is to use industry benchmarks to establish a projected cost, which the group can use as a standard to measure proposed changes to tools and process flows. The benchmarks can be used to set an initial cost target. There is a cost program that sets the target cost for the various process technologies to drive productivity and competitiveness. The purpose of target costing is to influence behavior, not accurately calculate costs.[79]

7.3 Target costing approach

The target costing approach to managing costs during product and process development (Section 6.4) illustrated in Figure 11 is used to develop a cost model for the GEN-Q semiconductor process and consists of three parts: 1) the target cost is determined by the cost program for the GEN-Q process, 2) a baseline cost is established that shows the cost for the silicon if no progress is made on cost reductions project, and 3) a project tracking system that is used to track cost progress from the baseline towards the target. The target cost was set by the cost program before the internship, and then the baseline set model and project tracker were developed during the internship.

79 Alles, pp. 1-15.



Modified/ recommended Figure-11

Figure 11: Target cosr model approach

Target cost

The silicon target cost is established by a cost program. The target cost value typically remains constant unless there is an unexpected event in the market place, such as the introduction of a new competing product from a competitor or a significant change in consumer preferences. The methodology for establishing target costs is described in Section 7.4.

Baseline cost

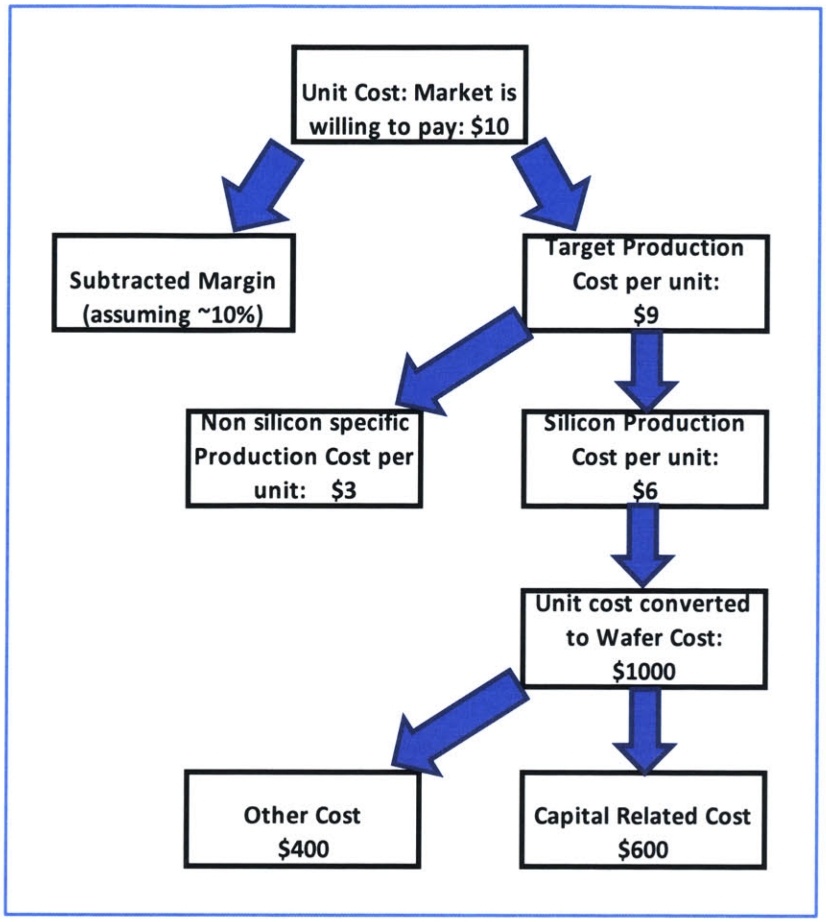
The baseline cost of the silicon (the expected cost if no changes are made from what is known today) is set at the beginning of the development process. This cost will remain constant until there are significant changes in silicon production forecasts. Significant forecast changes can occur several times per year and require the program manager to request a reset of the baseline costs. The baseline cost model is described in more detail in Section 7.5.

Project cost tracker

The project cost tracker model is that is used to track progress from the costs established with the baseline cost model towards the target silicon cost. Individual projects are given a high, medium, or low confidence of completion ranking to determine how level of effort required by the development team reach the target. The project cost tracker is updated regular basis to provide status on projects and progress to meeting the target. This gives the ability to track and report progress to other groups that can make informed business decisions. The project tracker cost model is described in more detail in Section 7.6.

7.4 Wafer target cost

Target costing is used to motivate the product and process development team to develop a semiconductor process that is affordable in the market place. 80 First, market research is completed to determine the selling price for the future end product. Then, the market price is used to determine target costs for the individual cost components of that product. The Capital Equipment Procurement group at Intel is interested in the target cost for capital equipment that is used to produce a semiconductor wafer. The process used to set the target cost for the semiconductor processing capital equipment is illustrated in Figure 12 and explained below.



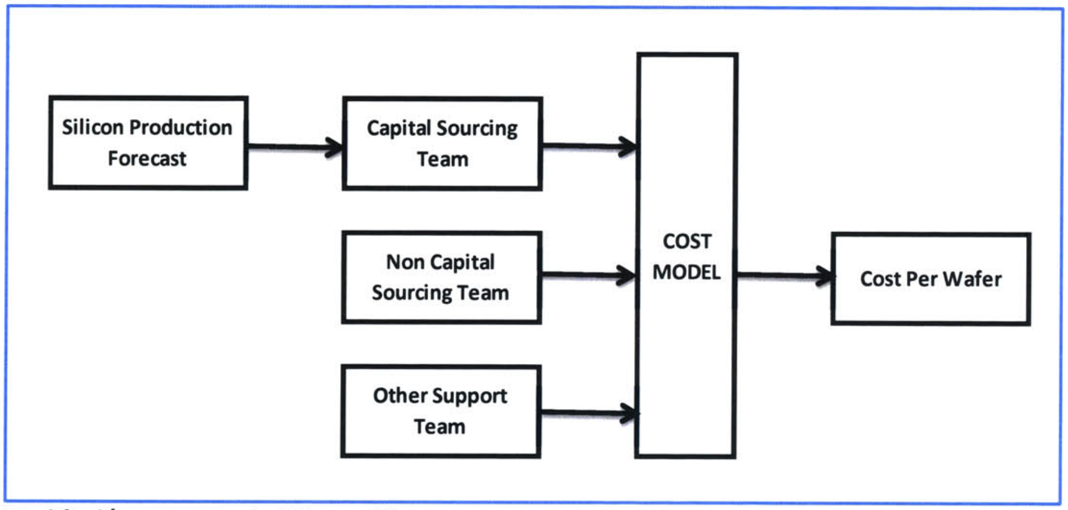
Modified/ recommended Figure-12

Figure 12: Wafer target cost

The costs in this example are fictitious and are not representative of actual costs or margins at Intel. In this example, the market has determined that the future cost that a customer is willing to pay for a new chip is $10. Subtracting the 10% margin the manufacturer expects to make results in the $9 required cost to manufacture the chip. The two major parts of a chip are the package and the semiconductor die, which must cost $6 to be affordable. The cost to produce a semiconductor die is typically divided into front-end and back--end costs. Assuming that there are 250 die per wafer for this product, the front-end cost per wafer must be $1000 for the product to be affordable. If the cost to produce the wafer is less than $1000, then the product will be profitable. This gives the development team within MES a target cost of $600 per wafer for the capital equipment used to produce the product.

7.5 Cost model to set baseline cost

A functional diagram of the cost model that is used to set the baseline costs is shown in Figure 13. As is the case for all semiconductor companies with installed equipment based, the process technologies used a mix of existing and new equipment determined by demand forecast mapped against the capcity and capability in place within the factory system. In this section, we identify the areas that are included in the model, identify areas that are excluded from the model, and then describe each of the included areas capital, non-capital requiring sourcing, and other support required in more detail.



Modified/ recommended Figure-13

Figure 13: Baseline cost set model functional diagram

7.5.1 Areas included in cost model

The following six areas were chosen to be included in the cost model because they are the largest contributors to total wafer cost that the Capital Equipment Procurement group has the ability to influence significantly:

- **Capital Sourcing:** Based on the process capability of existing factory and capacity available additional capital investments need to be made to meet the silicon production forecast for a given process technology. As is the case with all semiconductor manufacturing companies, this capital will be a mix of existing equipment technology and new equipment technology.
- **Non Capital Sourcing:** Since the technology will be deployed into existing factories and not in a green field site, there are also non-capital expenditures that are required to build the appropriate capability mix and capacity for the process technology that is being modeled.
- **Other Support:** Beyond the cost associated with the sourcing the appropriate capital and non-capital equipment and materials, there is other support required to configure the factory to handle the projected silicon forecast.

7.5.2 Areas excluded from cost model

There are many areas that contribute to total wafer cost that are not included in this cost model; Section 7.1 discussed some of these areas that CEP has no control over. However, some areas that CEP does have control over were nevertheless excluded because the expected cost savings is less than the cost required to produce the cost savings. For example, the chemicals and gases used to process a wafer are not included. While these make a significant contribution to total wafer cost, they are not included because the Capital Equipment Procurement group does not typically make decisions based upon the costs for the chemicals and gases (these decisions have generally been made as part of product and process development). There are unique cases where special circumstances (such as newer equipment that uses less energy, water, chemicals, etc.) require the inclusion of costs that are not included in the cost model. These cases are dependent upon the equipment engineer's expertise to understand them and include them in the project cost tracker that is discussed in Section 7.6. The project cost tracker facilities decisions such as determining when buying a new piece of equipment creates lower total cost of ownership than keeping an old one.

7.5.3 Capital Sourcing:

The capital cost is the cost for all of the semiconductor processing tools that must be purchased or allocated for the GEN-Q process. Some products produced with the GEN-Q process are highly price sensitive, so it is important to generate the most cost effective capital equipment profile that meets the process capability.

Tool list, quantities, and costs

A list of all of the types of tools required for a process, along with the quantities and costs for those tools, are all pulled from a corporate database into the cost model spreadsheet. Tool types, quantities, and costs are constantly changing as the process matures, negotiations are completed with suppliers (such as volume discounts), and long-range wafer forecasts change. In order to provide a fixed baseline, these values are pulled once to set the baseline and then are not changed until the program requires a baseline reset. All tool type, quantity, and cost changes after the baseline has been set are tracked.

Long Range Plan and tool allocation

Product demand forecasts are converted into forecasted wafer starts for individual products, processes, and fabs. This information feeds the capital equipment profile to support the GEN-Q process.

Cost per wafer calculation

The total cost for all of the capital required for the process is known once the individual tool types, quantities, and costs are known. This total cost and the total number of wafers processed over the life of the tool are used to calculate a cost per wafer. The model includes the costs for all of the products that will be produced.

Update process

Once all of the tools are identified, the costs can be updated at any time. There are two steps required to update the new capital cost. The first step in the update process is to update quantities and prices for all of the existing tools. The second step is to scan the database to identify any new tools that must be added to the model when they appear.

These updates are made after significant changes in the long-range wafer forecasts, which typically occur several times per year. The updates could be made on a more frequent basis, but doing so would only add confusion to an already complicated process.

7.5.4 Non-Capital Sourcing:

Spares and consumables contribute to the cost of production. These costs are not considered to be capital costs since the cost or useful life is below the threshold established for capital and depreciation. These cost cannot be ignored as they can constitute a significant portion fot he total cost of ownership. The non-capital costs are more linear with wafer volumes since consumables are associated with the processing of wafers rather than the step function associated with putting equipment in place to handle the forecasted volumes. One of the challenges with the GEN-Q process is that it uses a mix of tool generations that have a variable distribution of spare and consumable useage.

A representative from the spares organization is responsible to provide the estimated spare cost for a given process. Although this number might not be perfectly accurate, it provides a baseline against which progress can then be shown.

7.5.5 Other Support:

Service is a major component of other support needed for the equipment set. The service cost is the cost associated with supporting a tool over its useful life. This cost is becoming increasingly important and increasingly difficult to correctly allocate to individual processes. The service cost includes the number and type of support people required at each site to provide a guaranteed response time. There are several factors that make this difficult to calculate. Attempting to calculate a support cost for a single process technology is difficult when the process is going to be run at different locations that have different support costs.

One of the goals for the creation of this model was to include the capability to make informed decisions on capital equipment purchases that included the costs of spares and service in addition to the cost to purchase the capital equipment. The model achieves the goal in part because the model shows major impacts to service. The actual service costs are unknown until the process technology is produced in a volume manufacturing facility.

There is a potential opportunity for suppliers to make up for low margins on new tools by increasing service costs. This is a business model that has been successfully used in a variety of different industries (for example, jet engine manufacturers routinely sell engines below cost and then make money over the lifetime of the engine by providing service and spare parts). All of these factors combined make it very difficult to accurately predict service costs at a time when it is increasingly more important as suppliers use service contracts as a way to increase profitability.

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7.6 Project cost tracker

As discussed above, Intel wants to maximize profitability in the face of decreasing microprocessor selling prices and its increasing reliance on other chip types. The Capital Equipment Procurement group can contribute to this company goal by influencing affordability. To do this, they need a roadmap that shows starting costs, cost reductions to date, and target costs for individual process technologies. In addition to the high level status they need to understand how both supplier parameters and productivity changes affect wafer cost. Another benefit obtained from this tool is the ability to show the broader Intel organization exactly what the Capital Equipment Procurement group has contributed to the business objectives of Intel to achieve affordable process costs.

7.6.1 Project cost tracker description

The project cost tracker is a spreadsheet that is used to track projects and the cost deltas associated with them. The interesting parts of the project cost tracker are the column definitions and the process in which it is used. The definition of confidence and cost impact, the process, and some of the tradeoffs that were made in developing the project cost tracker are explained in more detail in the following paragraphs.

Cost impact

There are two alternative ways to document the costs associated with a project. One method is to include separate columns for each cost in the cost model capital cost, non-capital cost, support cost.

The second method, which was determined to be preferable, is to include only one cost column that summarizes the combined impact to wafer cost. The project owner still has to calculate all of the different cost areas that are impacted by a project, but then he or she summarizes the total wafer cost impact and documents that total cost impact in the project cost tracker. It is important to calculate the total wafer cost impact because suppliers will reduce new equipment costs, but then increase spare costs and service costs.

This creates the initial appearance that costs are reduced, but in reality the overall cost often stays the same.

An opportunity for improvement in the project tracker is the inclusion of cost ranges since actual cost impacts are typically not known exactly. The cost impact usually covers some range which requires the project cost owner to pick a value to enter. The project cost tracker could have been developed to include a sensitivity range, but the added benefit was determined to not outweigh the added complexity.

Confidence Definitions

There are multiple different factors (technical feasibility, resource availability, and project approval) that together determine the confidence definition. A project is classified as high confidence if the project is technically feasible, resources are available, the cost estimate is complete, and the project has been approved. A project is classified as medium confidence if the project is technically feasible, resources are available, and the cost estimate is complete but the project has not been approved. A project is otherwise classified as low confidence.

7.6.2 Project cost tracker usage process

A core affordability team meets on a weekly basis to discuss affordability at a high level and uses the project tracker as a status tool. Various issues are addressed as appropriate and input is received from all of the members.

The entire affordability team, meets once a month in a common location to discuss status, generate new ideas and get different perspectives. Since the affordability team is distributed, the monthly provides a good forum to solve problems in a team basis with everyone in the same location. The entire team is able to provide feedback and suggest alternatives where additional cost savings can be found.

7.6.3 Cost accuracy dependence upon users

One of the issues with this type of project cost tracker is that the accuracy of the cost model is dependent upon the people who input the cost data. Local data control increases accountability by requiring the users to be completely responsible for determining and inputting the correct information. Additionally, this gives the program manager the flexibility to present data that is the most accurate representation of the current program costs.

7.7 Example of cost model usage

Typical modem semiconductor processes consist of several hundred processing steps performed on around one hundred unique tools. The cost model required to manage the product development for this complex manufacturing process includes hundreds of individual tools and their associated performance and cost parameters. In this section, a simplified model is used to show how the complex model functions and to illustrate some of the issues that arose during its usage.

First step: Set the tool baseline cost and equipment target cost (Table 13)

The target cost model approach begins with the calculation of the baseline costs for all of the tools and the calculation of the target cost for all of the tools summed together. For example, the unit capital cost for Tool A of $11 million is multiplied by the 6-tool quantity to get the total tool capital cost of $66 million. The $11 million estimated cost for Tool A comes from a variety of different sources, which are dependent upon the status of the tool's development. The 6-tool quantity includes all currently planned implementations of this process at multiple facilities and is dependent upon the wafer processing capability of the tool. A separate model is used to determine tool quantity requirements for individual processes.

The $66 million Tool A capital cost is converted into a $31.70 depreciation cost per wafer by spreading the cost of the tool over the total number of wafers that the tool is expected to process over the depreciation life of the tool. This expected cost may change over time, but is calculated with the best-known information for future production volume and tool processing capacity.

The $38.70 total tool cost for Tool A is comprised of the sum of the capital depreciation, spares cost, and service cost. The $7 for spares and service are both calculated by other groups which are responsible for spares and service issues. The total tool cost for all of the tools are summed together to get the $400 total cost per wafer, which is greater than the $350 target cost which must be met for the product to be affordable in the marketplace.

unit			total					
Tool Tool A	**quantity** 6	**capital cost (M$)**11	**capital cost (M$)**66	**capitaldep ($/WS)**31.7	**spares cost ($/WS)**3	**service cost ($/WS)**4	**total tool cost ($/WS)**38.7	**target cost ($/WS)**
Tool B	7	21	147	70.7	2	1	73.7	
Tool C	2	31	62	29.8	6	4	39.8	
Tool D	1	21	21	10.1	1	2	13.1	
Tool E	9	18	162	77.9	2	1	80.9	
Tool F	5	28	140	67.3	4	5	76.3	
Tool G	3	15	45	21.6	2	2	25.6	
Tool H	1	26	26	12.5	2	1	15.5	
Tool I	2	5	10	4.8	3	3	10.8	
ToolJ	1	31	31	14.9	5	6	25.9	
Total			**710**	**341**	**30**	**29**	**400**	**350**

Table 13: Tool baseline cost and equipment target cost

Second step: Set the tool level target costs (Table 14)

Given the overall targeted cost of the wafer and the estimated cost if no changes are made, the cost reduction required is calculated. This total cost reduction is achieved at the individual tool level, so targets must be set at the tool level. The two common ways to set tool level targets are from the top-down and from the bottom-up. In the top-down approach it is assumed that every tool, no matter its cost and current capability, has the same percentage wise ability to improve. The bottom-up approaches looks carefully for opportunities for each tool before determining the target.

. Required cost reduction percentages were initially spread evenly across all of the tools where the contracts were not signed off. Table 14 illustrates this by showing equivalent cost reductions for all tools except for Tool B, which is assumed to have a closed purchase contract that could not be reopened. Then, equipment engineers worked on performance improvements and commodity managers worked on price reductions to reduce the overall cost.

unit			total					
Tool	**quantity**	**capital cost**	**capital cost**	**capitaldep**	**spares cost**	**service cost**	**total tool cost**	**target cost**
Tool A	6	(M$)11	(M$)66	($/WS)31.7	($/WS)3	($/WS)4	($/WS)38.7	($/WS)32.8
Tool B	**7**	**21**	**147**	**70.7**	**2**	**1**	**73.7**	**73.7**
Tool C	2	31	62	29.8	6	4	39.8	**33.7**
Tool D	1	21	21	10.1	1	2	13.1	**11.1**
Tool E	9	18	162	77.9	2	1	80.9	**68.4**
Tool F	5	28	140	67.3	4	5	76.3	**64.5**
Tool G	3	15	45	21.6	2	2	25.6	**21.7**
Tool H	1	26	26	12.5	2	1	15.5	**13.1**
Tool I	2	5	10	4.8	3	3	10.8	**9.1**
Tool J	1	31	31	14.9	5	6	25.9	**21.9**
Total			**710**	**341**	**30**	**29**	**400**	**350**

Table 14: Tool level target costs

Update Example 1: Productivity improvement and price reductions (Table 15)

This update example illustrates three cost reductions including a productivity improvement, a revised cost estimate, and a contract negotiation. A productivity improvement is identified on Tool C that results in a reduction in the quantity of tools required from two tools to one tool resulting in a $14.9 cost savings per wafer. Additionally, the initial cost estimate for Tool D is determined to be 15% higher than the revised expected cost, which translates into a $1.50 cost savings per wafer. A contract negotiation is completed with the Tool E supplier, which results in a 10% cost savings per Tool E. These productivity improvements and price reductions reduce the total cost per wafer from $400 to $376.

These cost reduction opportunities are tracked with the cost project tracker that is discussed in Section 7.6. Equipment engineers and commodity managers that are responsible for the individual tools identify potential cost reduction projects and then input them into the cost project tracker. Management reviews the projects and then determines which ones will be pursued based upon confidence, risk, and expected impact. After the project is approved and completed, the new tool performance and cost are updated in the appropriate databases.

Tool	quantity	unit capital cost (M$)	total capital cost (M$)	capital dep ($/WS)	spares cost ($/WS)	service cost ($/WS)	total tool cost ($/WS)	target cost ($/WS)
Tool A	6	11	66	31.7	3	4	38.7	**32.8**
Tool B	7	21	147	70.7	2	1	73.7	**73.7**
Tool C	**1**	**31**	**31**	**14.9**	**6**	**4**	**24.9**	**33.7**
Tool D	**1**	**17.85**	**17.85**	**8.6**	**1**	**2**	**11.6**	**11.1**
Tool E	**9**	**16.2**	**145.8**	**70.1**	**2**	**1**	**73.1**	**68.4**
Tool F	5	28	140	67.3	4	5	76.3	**64.5**
Tool G	3	15	45	21.6	2	2	25.6	**21.7**
Tool H	1	26	26	12.5	2	1	15.5	**13.1**
Tool I	2	5	10	4.8	3	3	10.8	**9.1**
Tool J	1	31	31	14.9	5	6	25.9	**21.9**
Total			**660**	**317**	**30**	**29**	**376**	**350**

Table 15: Productivity improvement and price reductions

Update Example 2: Tool allocation shift and negotiated cost reduction (Table 16)

This update example illustrates a simultaneous tool allocation shift and negotiated cost reduction, which when combined result in no significant change in the total cost per wafer. Table 16 shows that a $4.6 million cost reduction achieved on Tool F can be offset by an increase in the quantity of tools required from 5 tools to 6 tools. This tool quantity change can occur when there is a change in the long-range forecast, which causes a reallocation of reused tooled. In this example, one Tool F that was previous going to be reused is no longer available, so an additional Tool F must be purchased increasing the tool quantity.

In this simple example it is easy to follow these two simultaneous changes, however in the full model it is difficult to track such changes if they are not carefully documented. This can be confusing as shown in this example where a significant cost reduction is achieved on an individual tool, but there is no change in the total tool cost per wafer. One option to help clarify this issue is to have multiple columns for each tool showing new tool purchases and reused tools. This approach was not chosen for this example to keep it simple.

Tool	**quantity**	**unit capital cost (M$)**	**total capital cost (M$)**	**capital dep ($/WS)**	**spares cost ($/WS)**	**service cost ($/WS)**	**total tool cost ($/WS)**	**target cost ($/WS)**
Tool A	6	11	66	31.7	3	4	38.7	**32.8**
Tool B	7	21	147	70.7	2	1	73.7	**73.7**
Tool C	1	31	31	14.9	6	4	24.9	**33.7**
Tool D	1	17.85	17.85	8.6	1	2	11.6	**11.1**
Tool E	9	16.2	145.8	70.1	2	1	73.1	**68.4**
Tool F	**6**	**23.2**	**139.2**	**66.9**	**4**	**5**	**75.9**	**64.5**
Tool G	3	15	45	21.6	2	2	25.6	**21.7**
Tool H	1	26	26	12.5	2	1	15.5	**13.1**
Tool I	2	5	10	4.8	3	3	10.8	**9.1**
Tool J	1	31	31	14.9	5	6	25.9	**21.9**
Total			**659**	**317**	**30**	**29**	**376**	**350**

Table 16: Tool allocation shift and negotiated cost reduction

Update Example 3: Conversion kit with higher total cost of ownership (Table 17)

This update example illustrates a case where the total cost of ownership for reusing a used tool is more expensive than purchasing a new tool. Table 17 has three rows for Tool I, so that a comparison can be made between purchasing a new tool, reusing existing tools, or purchasing a conversion kit for an older tool. The cost comparison column is included so that the three options can be compared to choose the option with the lowest cost which is shown in the total tool cost column.

In this example, the two options that are available are the purchase of a new tool or the conversion of an older tool, since there are no tools available for reuse. Typically, it is preferable to purchase conversion kits since they are significantly cheaper than new tools. However in this case, the added spares and service costs associated with the conversion kit option increase the total tool cost from the new tool option of $10.80 to $12.90 per wafer for the conversion kit option. This shows the importance of calculating the total cost of ownership instead of only considering the capital purchase price in a purchasing decision.

Tool	qty	umt capital cost (M$)	total capital cost (M$)	capital dep ($/WS)	spares cost ($/WS)	service cost ($/WS)	cost comp ($/WS)	total tool cost ($/WS)	target cost ($/WS)
Tool A	6	11	66	31.7	3	4		38.7	32.8
Tool B	7	21	147	70.7	2	1		73.7	73.7
Tool C	1	31	31	14.9	6	4		24.9	33.7
Tool D	1	17.85	17.85	8.6	1	2		11.6	11.1
Tool E	9	16.2	145.8	70.1	2	1		73.1	68.4
Tool F	6	23.2	139.2	66.9	4	5		75.9	64.5
Tool G	3	15	45	21.6	2	2		25.6	21.7
Tool H	1	26	26	12.5	2	1		15.5	13.1
Tool New	2	5	10	4.8	3	3	10.8	10.8	9.1
Tool-Reuse	N/A	0	0	0.0	0	0	N/A	0.0	9.1
Tool-Conv. Kit	2	2	4	1.9	5	6	12.9	0.0	9.1
Tool J	1	31	31	14.9	5	6		25.9	21.9
Total			663	319	35	35		376	350

Table 17: Conversion kit with higher total cost of ownership

Achievement of total equipment cost reductions (Table 18)

The last table in this example shows that the total tool costs are reduced to $349, which is lower than the $350 target cost. The cost reduction project is considered complete since the target cost per wafer goal has been surpassed.

			total					
Tool	**quantity**	**capital cost**	**capital cost**	**capitaldep**	**spares cost**	**service cost**	**total tool cost**	**target cost**
Tool **A**	5	**(M$)**9	**(M$)**45	**($/WS)**21.6	**($/WS)**3	**($/WS)**4	**($/WS)28.6**	**($/WS)32.8**
Tool B	7	21	147	70.7	2	1	**73.7**	**73.7**
Tool C	1	31	31	14.9	6	4	**24.9**	**33.7**
Tool D	1	17.85	17.85	8.6	1	2	**11.6**	**11.1**
Tool E	9	16.2	145.8	70.1	2	1	**73.1**	**68.4**
Tool F	6	23.2	139.2	66.9	4	5	**75.9**	**64.5**
Tool G	3	11	33	15.9	2	2	**19.9**	**21.7**
Tool H	1	17	17	8.2	2	1	**11.2**	**13.1**
Tool I	2	5	10	4.8	3	3	**10.8**	**9.1**
Tool J	1	21	21	10.1	5	4	**19.1**	**21.9**
Total			**607**	**292**	**30**	**27**	**349**	**350**

Table 18: Achievement of total equipment cost reductions

At this point, the organization typically turns its attention to other projects. However, the situation may exist where there are additional opportunities for further cost reduction. Management should review the overall process before confirming that resources should be reallocated to other projects.

7.8 Chapter summary

In this chapter, semiconductor processing capital equipment cost models for the Capital Equipment Procurement group within Intel are discussed. First, the target cost model approach is explained and then the cost model is described in detail. The chapter ended with an example showing how cost models are used to manage costs. In the next chapter, we critically analyze cost systems used at Intel within CEP showing both the industry best practices that have been followed and opportunities for improvement.

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Chapter 8: Critical analysis of cost systems

In this chapter we critically analyze the cost systems that are used within the Capital Equipment Procurement group at Intel. First, we show how Intel has successfully incorporated target costing principles into their cost systems and has followed many of the best practices in target costing. Then, we discuss four opportunities for improvements in their cost systems: 1) increase cost focus on commodity products, 2) improve the process used to set target costs,3) replace point cost estimates with range estimates, and 4) follow the cardinal target costing rule: never change the target cost.

8.1 Target costing best practices currently followed at Intel

Target costing was originally developed and used successfully within Japanese companies. Today, transportation and heavy equipment industries in the United States are adopting target costing. These industries are characterized by intense competition, extensive supply chains, and relatively long product cycles. A recent study to benchmark best practices in target costing identified The Boeing Company, Caterpillar, Continental Teves, and DaimlerChrysler as companies that have the best practices in target costing.[81]

All of the companies in the study were consistent in the target costing approach, which is similar to Intel's approach. Four of the best practices that exist at these model companies include utilizing a cross-functional organization structure, listening to the voice of the customer, emphasizing cost reduction during the new product development cycle, and effectively removing costs throughout the supply chain.

At DaimlerChrysler, a toolbox of management initiatives including value engineering, value analysis, design for manufacturing assembly, paper kaizen, and lean manufacturing are used by cross-functional teams to improve productivity and reduce costs. These activities occur in workshops where teams of five to thirty individuals meet from one to five days to solve problems and improve operations.

Customers are actively solicited by Boeing to determine what features a customer is willing to pay for and what price that customer is willing to pay. For example, one of Boeing's customers requested heated floors which before target costing would have been provided without regard to price. Since the company now prices airplane options

[81] Swenson, pp. 12-17.

separately, the company that made the request decided against the heated floors after discovering that they were going to cost an additional $1 million.

At Continental Teves, approximately 75% of the value of their products comes from purchased components. In this environment, target costing would be almost impossible to achieve without the participation of suppliers. Target costs are set for every part and then given to a supplier. If the supplier is not able to meet the target cost, Continental Teves will ask to send a team to the supplier to help determine what must be improved to meet the targets.

Intel has successfully incorporated the following target costing principles (see Section 6.4) into their product and process development process:

- **Price-led costing:** End product market prices are used to determine allowable product costs from which the allowable semiconductor processing equipment costs are derived.
- **Focus on customers:** Customer requirements for quality, cost, and time are simultaneously incorporated during product development for both the end product and for the semiconductor processing equipment. MES interacts with the production factories who are the end customers for the equipment.
- **Focus on design:** Cost control for the semiconductor processing capital equipment is emphasized during the product and process design stage of the development cycle.
- **Cross-functional involvement:** Cross-functional teams are involved from the early design through production. Involving these teams in the target costing process encourages communication, which improves the product development process.
- **Value chain involvement:** Intel works closely with the equipment suppliers who are the most important member in their value chain.
- **Total cost of ownership:** The cost models account for the total cost of ownership by including items such as installation, operating, spare parts, and maintenance costs in addition to the equipment purchase cost. For the companies in the study, and for Intel, target costing has proven to be an

effective means of cost control. The relatively small costs associated with implementing target costing at these companies is smaller than the benefits that are obtained by making better informed decisions on expensive pieces of capital equipment.

8.2 Recommendation: Increase focus on target costing

Intel can learn about the increasing importance of target costing from experience gained at Black & Decker, where target costing took on a new level of importance in the mid 1990s.[82] Traditionally, Black & Decker had been first to market with innovative products and was able to command a premium price point. This changed as fast followers became much better at copying Black & Decker's products in a shorter amount of time requiring a changed focus on cost competitiveness.

To address this new competition, target costing was incorporated into the product development process. Project teams that had previously focused on innovative products openly discussed profitability requirements at project meetings. Project teams met regularly with end users and account representatives to determine which features should be included in the new product and how much a customer would be willing to pay for that new feature. Manufacturing costs were improved by standardizing parts such as motor and drivetrain platforms and involving suppliers in cost reductions. Target costing brought together a project team of end users, customers, suppliers, and developers that was able to successfully develop new products that are competitive in the marketplace.

Intel now faces a situation that is similar to Black & Decker's. Traditionally Intel has produced high performance microprocessors that were able to demand a premium price. Today, Intel is producing more commodity products, such as communication and flash products, which typically have lower margins. In these commodity markets, Intel has to compete on price and not purely on performance which requires more focus on cost during the product and process development cycle. The proper use of cost management techniques such as target costing will enable to Intel to lower costs on commodity products. Intel's recognition of this opportunity is demonstrated by the request for the development of the commodity product cost model that is developed in this thesis. To obtain further benefits, the cost model should be applied to additional semiconductor processes during product development.

[82] Gierke, p. 178.

8.3 Recommendation: Improve the target cost setting process

Intel can potentially benefit from incorporating some of the best practices from the literature in the process used to set target costs. The target costing approach is much different from the design to cost approach where a cost target is thrown over the wall and the developers attempt to achieve it. Target costing integrates strategy, marketing, market research, and strategic supply chain management into the process and has been proven to produce better results than design to cost.[83] An important part of the target costing process is the methodology used to set the target cost. Some of the target cost setting best practices that could be incorporated at Intel includes involving the development employees, setting tip-toe objectives, and involving the value chain.

Development employee involvement

The positive effect of participation in target cost setting on cost reduction performance is shown in the literature.[84] A target cost can be set either top-down, where the target cost is imposed on the cost reduction team, or the cost can be set bottom-up, where the team is involved in the target cost setting process. In the bottom-up approach, the cost reduction team members participate in a series of negotiations where they determine an attainable target cost for every part of the product. The part owners and the product owner negotiate back and forth until an agreement is reached on the target cost. The participation in this process provides the team members with a stronger feeling of ownership that provides an incentive to achieve the agreed upon target costs.

83 Cooper, pp. 88-97.
84 Monden, pp. 1 13-129.

Tip-toe objectives

It is important that employees see that target cost objectives are transparent, valid, and achievable most of the time. Setting cost targets that are too high and not achievable is no different from setting no targets at all. The Japanese set target cost objectives that may be reached by "standing on tip-toes."[85] The goal is to stretch the organization by setting objectives that can barely be reached, but are successfully reached most of the time. This is important so that employees believe the objectives are valid and obtainable. However, using this technique to set objectives will increase the future effectiveness of the target cost process by establishing an environment where stretch goals are continually achieved.

8.4 Recommendation: Incorporate expected cost ranges into cost systems

A model that incorporates cost distributions instead of point cost estimates provides a more complete picture of expected costs. One way to accomplish this is to use a Monte Carlo analysis which is a quantitative simulation technique that takes cost inputs as probability ranges and outputs an expected cost distribution. Lorance (1999) shows how a Monte Carlo analysis is used to provide a more complete picture of costs over a project lifecycle. In the article, a Monte Carlo analysis is used to show expected cost ranges for a project at an oil company. Initially during the screening phase, the 80% confidence interval for the cost was -50% to +100% of the estimated cost value. The cost range was reduced to -40% to +60 % during the conceptual phase and then further reduced to -18% to +25% during the definition phase. Finally during the design and construction phase the range was reduced to -8% to +6%.[86] The additional information from the Monte Carlo analysis was used to make more informed decisions during the project leading to the successful completion of the project within the cost goals.

One potential area for improvement at Intel is to incorporate expected cost ranges into cost systems instead of using point cost estimates. Intel's cost systems use point estimates for individual equipment costs that are summed together to arrive at the total

85 Cooper, p. 97.
86 Lorance. pp. 1 -10.

capital equipment cost. This gives the impression that all of the costs are known exactly with the same level of certainty, when they are actually often unknown and estimated. Costs along with many other items are often unknown early in the product and process development cycle.

Employees responsible for the capital equipment costs are required to reduce costs over time. The incorporation of cost distributions provides the employees the ability to show expected ranges instead of point estimates. For example, the cost team objective for a tool with a wide cost distribution will be to find out more information to determine more precisely how much the tool is going to cost. The objective for a tool that has a narrow cost distribution will be to reduce the tool cost since the cost is known with a high degree of certainty.

Crystal Ball by Decisioneering Incorporated is a software tool that has Monte Carlo analysis simulation capability and is easily integrated into common spreadsheet programs. If Intel incorporates distribution information and modeling into the cost models, they will have more information available to make better informed decisions regarding cost during product and process development.

8.5 Recommendation: Follow the cardinal target costing rule

Another area for potential improvement at Intel involves fixing the target costs and not changing them. Cooper identified the cardinal target costing rule: "If you cannot meet the targets, you cannot launch the product."[87] When the target cost is set correctly, a product that does not meet the target cost should not be launched into the marketplace since it will not meet the profit margins that the company requires. This cardinal rule is important to follow because it provides a consequence to the target cost value. If a product does not meet the target cost, it is not launched. Additionally, the target cost must also have credibility. The employees that are developing the product to meet a certain target cost must believe that the target cost is valid for it to provide the correct incentive to achieve it.

From observations during the internship it is not clear that all employees at Intel understand and follow this cardinal rule. For example, during the internship, the finance

[87] Cooper, pp. 96-97.

department requested a percentage cost reduction on service costs for Product A. A cost reduction team obtained a cost reduction for Product B that simultaneously also reduced Product A's cost. It was determined that this cost reduction would not be counted towards Product A's required cost reduction. This act broke the rule by changing the target costs in the middle of the project. This violation shows the employees that the target costs are not real targets. A better response would have been to not change the target costs, but instead to tell the employees that the target had been achieved successfully and further reductions will increase product profitability. Practices such as changing the target cost must be halted and the cardinal rule should be followed to maximize the effectiveness of the target costing process.

8.7 Chapter summary

In this chapter, cost systems within CEP at Intel were first analyzed to show that Intel successfully uses many of the industry's best practices for cost systems. Then, we discussed several opportunities to expand upon the prior successes in cost system implementation to address the future as market conditions change. If Intel continues to expand into commodity markets that have lower product margins, it will be increasingly important for Intel to address product costs in more detail during product development.

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Chapter 9: Final thoughts

This thesis has discussed risk and cost systems that are used for program management in the Capital Equipment Procurement group at Intel. After reviewing literature, the existing and new systems were discussed and then critically analyzed. In this final chapter, we review some of the key lessons learned that are important in the effective implementation of program management systems.

9.1 Program management systems evolve over time to maximum effectiveness

Program management frameworks such as the PMBOK risk framework provided by the Program Management Institute become highly effective systems after they have been used and fine-tuned over multiple generations of product development within a company. At Intel, the manufacturing readiness risk methodology has been fine tuned into a highly effective program management tool. This is an iterative process that is never completed and must be repeated at the end of every project. The current risk ranking questionnaires incorporate multiple generations of lessons learned that are specific to the needs of the CEP group. Often, lessons learned are documented and then put away somewhere where they will not be referred to on the next project. By incorporating lessons learned into the risk assessment, they will not be forgotten.

The new technology development risk assessment methodology will similarly be fine-tuned to obtain maximum effectiveness. Since the new system is similar to the existing system, this optimization process will occur much quicker than it did on the first system.

Another reason that the program risk management system becomes more effective over time is that the organizational knowledge grows. Intel's effective risk system cannot be duplicated immediately at another company because there is no way to duplicate the organizational knowledge that has been developed over many years. Program management systems of this type become very specific to an organization, as they are adapted over time.

9.2 Risk assessments allow employees to flag issues to senior management

One benefit that the risk assessment methodology provides is the ability for employees to raise potentially disruptive issues to senior management. For instance, it is possible that at some point in time a low-level employee might be aware of an event that will significantly alter the development of a new generation of process technology. The risk assessment methodology provides the opportunity for this employee's voice to be heard in front of a large diverse audience including multiple senior managers at review meetings held several times per year. At these meetings, a review of the high-risk items provides the opportunity for anyone who believes that a risk item is high to explain why to the entire audience.

Allowing employees to explain areas of concern directly to senior management is especially important at a company like Intel where there is a lot of data and information. During the internship, several senior managers explained that one of the key abilities of a successful manager at Intel is the ability to separate signals from noise. Often, important information (signal) is masked by a lot of information (noise) that is not as important. Risk assessment is one project management technique that successfully addresses this need by providing a forum where on a quarterly basis employees with concerns are allowed to communicate them directly to senior managers. All the concerned employee has to do is rank the tool that he is responsible for as high risk and he will be required to speak with senior mangers. This allows the managers to hear directly from employees who believe they have important information (signal) to communicate. Direct communication is the key part of the process because it allows the signal to be observed directly before the contents of the message are altered with noise as it passes through several layers of management.

9.3 Target cost models should be transparent and easy to use

The natural tendency for a high technology company such as Intel with a highly educated workforce is to develop complex financial cost models that accurately determine costs by tapping into every available corporate database. There are some cases where this is crucial to make the cost model as accurate as possible. However, there are also many cases where absolute accuracy is not the most important attribute of a cost model, but rather the ability to track differentials or changes in the costs is crucial. Equipment development engineers and commodity managers that are focused on developing and procuring new semiconductor processing tools use target cost models for program management. To support this effort, the models should be simple and easily track differentials or changes in costs. Developing a cost model that tracks costs to as many decimal places as possible does not always provide additional benefit to the users, so the additional investment for this type of development should not always be made. Instead, the model should be made as simple, transparent, and easy to use as possible.

9.4 Identify and manage key stakeholders

Introducing new program management systems into an organization is often a challenging task that can be simplified by understanding and managing the key stakeholders (i.e., people who are influential in implementing the new system). Buy-in should be obtained from the stakeholders during the initial project definition, throughout the project development, and then again before roll-out to the organization. It is easy to obtain consensus on the project objectives amongst a small team that is developing a system, but it is difficult, if not impossible, to obtain consensus amongst the users of the new system. Therefore, the successful roll-out of a new system to the broader organization is dependent upon support from key stakeholders that hold positions of influence throughout the organization.

Although in any project it is important to involve key stakeholders, it is especially important in the Capital Equipment Procurement group at Intel where employees deal on a daily basis with complex decisions regarding large investments. In this type of environment, it is important to thoroughly debate decisions that have potentially large financial impacts. However, some issues do not have major financial impacts and should be made swiftly without extended debates. If Intel continues to move into more commodity businesses with lower margins, it will be increasingly important for them to differentiate between the decisions that require extensive debate and the ones that need to be made swiftly. Some of the unnecessary debates that occur during the development and implementation of cost and risk program management systems can be minimized by the effective management of key stakeholders.

9.5 Conclusion

The Capital Equipment Procurement group at Intel requested two tasks: First, analyze and develop a risk assessment model that can be applied earlier in the product development cycle to ensure that the semiconductor processing equipment used to produce the next generation microprocessor is developed on schedule at an affordable cost. Second, analyze and develop a cost model for a new product to assure that the product is affordable when it is launched in the marketplace.

Overall, this thesis has discussed different systems that exist to manage programs from both a risk and a cost perspective. Although we discussed very specifically how these systems are currently used and how they can be changed, an important lesson is that program management is an iterative process calling for continual improvement to ensure product development success.

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Appendix A: List of risk sources

Pritchard (2001) identified the following list of risk sources. The list is not intended to be a comprehensive list of all possible sources of risk, rather it is included to show common ones identified by one group of people.

Risk
Capacity
Concept, failure to apply logistics support analysis during concept exploration
Concurrency
Configuration control of vendor products
Contracting, inadequate provision for support
Contractor, communication by
Contractor, lack of financial strength of
Contractor, production readiness of
Contractor, subcontractors and control of
Contractor, underbidding by
Coordination, inadequate
Data, inadequate planning for utilization of
Data, incomplete or inaccessible
Design, delayed definition of logistics criteria
Design, impact of engineering changes
Design, invalid application of component reliability and maintainability data
Design, lack of life-cycle cost impact on design and logistics support process
Design, unrealistic reliability and maintainability requirements
Design, stability
Engineering, late establishment of readiness and supportability objectives
Engineering, site survey results
Environmental impact
Equipment, common support
Failure to structure or tailor logistic support analysis requirements
Familiarization
Familiarization, tolerance levels
Fault detection
Funding, advanced buy authorization limitations
Funding, constraints on
Funding, long-term
Inflation
Integration/interface
Joint partner project decision
Labor disputes
Legal disputes
Legislation
Maintainability
Material properties

Modeling validity
Objectives and strategies
Operating environment
Operating policies
Personnel, available skills of
Personnel, downsizing and streamlining of
Personnel, forced placement of
Personnel, security clearances of
Physical properties
Planning, delayed facilities
Planning, delayed postproduction support
Planning, updating deployment
Policies, new
Priority
Project stretch-out
Radiation properties
Reliability
Scarce resources
Scheduling, accelerated acquisition
Scheduling, accelerated projects
Scheduling, decision delay
Scheduling, excessive lead times
Scheduling, slippage
Service roles and mission changes
Software design
State-of-the-art advances, lack of supporting
State-of-the-art advances, major
State-of-the-art advances, slow progress in
State-of-the-art advances, field failures
Survivability
Testing, extrapolation requirements
Testing, facility compatibility
Testing, incomplete or delayed support package of
Testing, inconsistencies
Testing, safety
Testing, security requirements
Testing, unrealistic scenarios for
Testing, weather
Threat changes
Uniquely harsh requirement
Vendor base

Table 19: Possible risk sources