Integrating Cost Consciousness into a High Quality Manufacturing Environment

by
Marie Carla Eustache

Bachelor of Chemical Engineering, City College of New York, 1996

Submitted to the Department of Chemical Engineering and the Sloan School of Management in Partial Fulfillment of the Requirements for the Degrees of
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Signature of Author ______________________________
Department of Chemical Engineering
& Sloan School of Management
May 7, 2003

Certified by ______________________________
Paula Hammond
Associate Professor of Chemical Engineering
Thesis Supervisor

Certified by ______________________________
Steve Graves
Abraham Siegel Prof of Management
Thesis Supervisor

Accepted by ______________________________
Margaret Andrews
Director of Master's Program
Sloan School of Management

Accepted by ______________________________
Daniel Blankschtein
Chair, Committee for Graduate Studies
Department of Chemical Engineering

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ABSTRACT

Intel Corporation, the world leader in manufacturing microprocessors, has been successful in achieving high margins because of its ability to successfully deliver high volume and reliable microprocessors at high demand. By ensuring the reliability and quality of the same product at multiple sites, Intel coordinated knowledge sharing across multiple facilities through a virtual factory, an approach known as "Copy Exactly". "Copy Exactly" methodology is a dominant force and integral part of Intel's culture in achieving high quality and high volume manufacturing. However, as the demand for microprocessors dropped in recent years, Intel focused more on lowering cost for higher margin earnings. Although lowering cost has been a normal process within Intel's operating environment, cost reductions usually occurred upfront during the product development period or the latter part of the manufacturing product life cycle. Between those stages, quality and output improvements were the primary focus. Cost reductions projects in manufacturing were delayed until sustainability stage. Intel initiated a paradigm shift on managing cost in manufacturing by pushing cost reduction projects earlier in the manufacturing product life cycle and moving accountability to groups that impact cost directly. The challenge of implementing this strategy posed is the focus of this thesis.

The LFM (Leaders for Manufacturing) internship at one of Intel's fabrication plant was developed to initiate and implement the commodity cost reduction program during production ramp. This thesis analyzes the challenges that Intel's manufacturing organization faces, while implementing a radical change in reducing commodity cost. By exploring the details of Intel's current organizational culture, technical strategy, and core competencies, the thesis describes how these factors affect the implementation and execution of the cost reduction program. By means of the concepts of reengineering as described by Michael Hammer, the cost reduction strategy will be analyzed for effectiveness. This program led the organization to focus on cost consciousness, while maintaining the high quality and reliability Intel is known for.

Sloan Advisor: Steve Graves
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1 Introduction

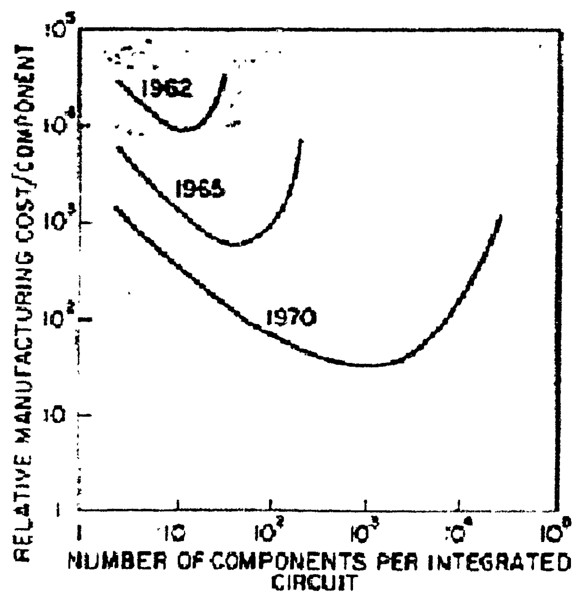
1.1 Company Overview

Intel, best known for its "Intel Inside" branding of the Pentium chip in 80% of the PCs, is the largest semiconductor manufacturer. Three engineers ---Robert Noyce, Gordon Moore, and Andy Grove --- established Intel in 1968. They invented the microprocessor, known as the "brain power" of the computing systems. In 1981, Intel became the sole supplier of microprocessors for IBM's' PCs. This resilient supplier-customer relationship with IBM elevated prominence to Intel's name and secured its position in the microprocessor market place. With the "Intel Inside" branding and the modular design of the IBM PC computer, multiple computer manufacturers used Intel microprocessors for their own PC brand. As competitors vie for market share, they advertise their quality by association with the "Intel Inside" logo. (Fig. 1.1-1) Intel has a dominant supplier power in this industry.

Fig. 1.1-1 Intel's Microprocessor with Logo

Intel amplifies the demand by relentlessly advancing its microprocessor technology. As formulated by Moore's Law, the product life cycle is 18-24 months with the doubling of transistors every two years. Fig.1.1-2. indicates the Cost Curve used by Moore for the advancement of integrated circuits. In addition, the need for more computing power due to software advancements, graphical enhancements and internet utilization increased the customer demand. This is a fast clock speed market. Therefore, there is a need to consistently develop quality products for computing systems. The product development group steadily delivered new product designs by pushing the envelope of Moore's Law, which increased chip performance and decreased cost per component. With new product introduction, the older microprocessors obsolesce and the demand for the new versions soared. Consequently, this strategy and market environment deterred new entrants into this market. Only a few can compete with brand, quality and lowering cost.

Fig. 1.1-2: Cost Curve indicates decreasing cost per component with doubling of transistors per chip.



During this high demand, Intel's main objective was to produce quality products in large quantity with fast speed to market. In order to meet the high demand, Intel adopted the "Copy Exactly" operating principle in 1990s, which increased their collaboration efforts in knowledge sharing across facilities. "Copy Exactly" is an operating principle that enforces the discipline and rigor of utilizing the exact same process for a product line in multiple facilities, globally. "Copy Exactly" enabled quality sustainability and maintenance across the manufacturing facilities. The "Copy Exactly" operating principle was a dominant factor in Intel's culture and a key enabler for producing high quality microprocessors in record speeds. Consequently, Intel has been able to maintain its strong hold and dominant supplier power in this market by inculcating the concept of "Copy Exactly" throughout the organization and pushing the envelope of "Moore's Law."

In the early 2000s, with the technology bubble burst, corporate accounting frauds, and the discussions of war, the financial market became unstable and placed a tremendous financial strain on many companies, including Intel. As the demand for computers and electronics plummeted, the demand for microprocessors decreased. In addition, Intel lost market share to stiff competition from low price manufacturers like AMD and price pressures from customers like Dell. Today, Intel, along with many other companies, is focusing on reengineering its business to achieve cost reductions, higher margins and long-term sustainability during this economic downturn.

1.2 Thesis Overview

As a result, the LFM internship at one of the Intel's fabrication plant, which will be called Fabrication Plant-7 in this thesis, was developed to address a new cost reduction program at the manufacturing level. The cost reduction program focused on commodity cost during the earlier stages of the manufacturing product life cycle, rather than the usual latter part of manufacturing product life cycle. Commodities consist of variable operating expenditures utilized during the manufacturing of the microprocessors, which were described as the following:

- Test wafers - dummy wafers used to validate and qualify process steps and equipment.
- Spare parts - maintenance parts to the equipment that were swapped out during a time based preventative maintenance (PMs) or wafer count preventative maintenance.
- Gas and Chemicals – material used to process the wafer. Example: slurry used to polish wafers.

This cost reduction initiative was a paradigm shift from the usual commodity cost management systems. Normally, commodity cost reduction projects in manufacturing occurred in the sustainable stage of the manufacturing product life cycle. The Manufacturing Systems Group with the support of finance was accountable for cost reductions in the manufacturing facility. In this new initiative, cost reduction projects would be implemented during the ramping of a new product line. In addition, this new cost reduction initiative would be focused on moving accountability of commodity cost to the process engineering group, who were primarily concerned with the quality and output of the product during ramp.

Internship Objective and Deliverables

The scope of the internship was to integrate commodity cost reduction into the process-engineering group at the Fabrication Plant-7 during production ramp. Since Fabrication Plant-7 was part of a virtual factory--- a virtual community consist of more than one fabrication plant collaborating on the production of the same product line--- Fabrication Plant-7 had to meet the virtual factory cost targets for each commodity. The targets were normalized based on the manufacturing facility's output, which were a more representative measurement for fabrication plant comparison. In consequence, this virtual factory, although not included as part of the scope of the internship, had a major impact on the implementation of the cost reduction initiative at Fabrication Plant-7, due to the collaboration efforts of process changes within the "Copy Exactly" operating principle. This virtual factory consisted of three additional fabrication plants. The following were the main deliverables for the internship:

- Define the process for cost management for the Process-Engineering Group.
- Integrate and provide the systems so that the process-engineering group can manage cost at various levels within the organization.
- Define and recommend an area for cost improvement.

The cost reduction program focused on strategy and organizational change within Fabrication Plant-7. This thesis examines the challenges the organization faced through three organizational frameworks: the strategic lens, cultural lens and political influence lens. The premise is to understand how the enterprise works in achieving its objectives and vision through these three frameworks. The strategic lens reveals where the organization is going. The cultural lens expounds on the human element and behavioral practices of the organization, like "Copy Exactly". Lastly, the political influence lens describes the distribution of stakeholders and the power in the organization. Furthermore, the thesis explores how the concepts of reengineering---the redesign of the work from functional to process-centric organization---affect the cost reduction strategy.

This **first chapter** framed the current business challenges the company faces in this industry. It provided insights on the purpose for implementing a new cost reduction program and a general overview of the thesis.

The **second chapter** will describe the challenges faced at Fabrication Plant-7 in implementing the cost reduction program through the three behavioral organizational frameworks: political structure, cultural mindset, and strategy. It will describe the previous cost structure of the manufacturing facility and how it will change. In addition, the second chapter will also explore how Intel Fabrication Plant-7's culture and political influence affect the cost reduction program.

The **third chapter** will describe the main factors that enable the reengineering of the business cost management process in manufacturing. The focus on a clear vision, education/communication, and automated systems facilitated the change.

The **fourth chapter** will illustrate a proposed automated system that will encourage and enforce discipline in cost management. With this system, more cost savings can be realized by focusing on rigor and awareness.

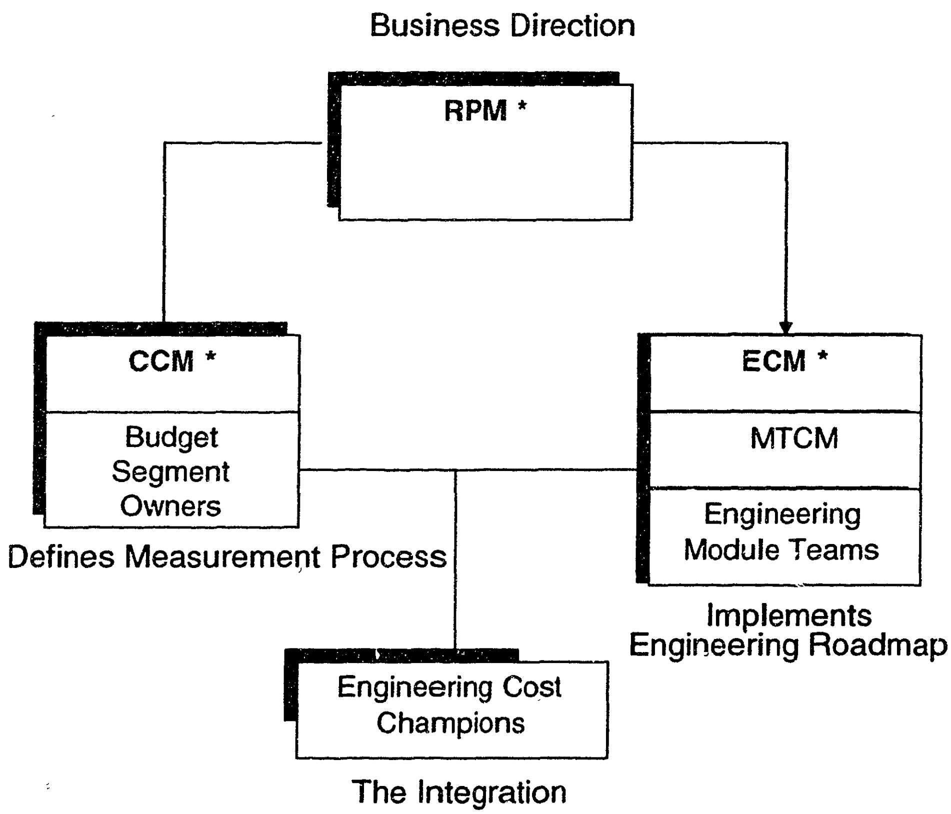
Finally, the **fifth chapter** will discuss conclusions and recommend steps for moving forward in cost management. It will also include the intern's observations, perceptions and reflections concerning Intel's culture and strategy.

2 The Organization

2.1 Who are the key players in the Cost Management Structure?

Knowing the key players in an organizational culture provides insights to the implementation of the plan. Louis V. Gerstner, former CEO of IBM, defines the nature of an organization in his book, Who Says Elephants Can't Dance in these terms: "An organization is nothing more than the collective capacity of its people to create value." The following core groups and teams facilitated the value-creating change in commodity cost management at Intel's Manufacturing Fabrication Plant-7. Figure 2.1.-1, includes the key organizational players of cost management at Fabrication Plant-7 and virtual factory. For clarification, the virtual factory teams are indicated with an asterisk in the figure. The engineering cost champion was added into the organization structure. The following description of the teams will provide a better understanding of the cost management system and structure at Fabrication Plant-7.

Fig. 2.1-1: Key Organizational Players of Cost Management



<u>Budget Segment Owners</u>

Budget Segment Owners were accountable in managing the commodity cost management structure for the facility. For each commodity, Budget Segment Owners forecasted the spending expenditures based on the learning curve, historical consumption data, benchmarking from industry standards and affordability data on the product. The Budget Segment Owners consisted of financing, purchasing and systems groups. The leader of this group was responsible for managing the spending expenditures and cost reduction programs during the operation of the plant. Although they were incentivized to reduce cost, they did not directly implement cost control in plant or cost reduction projects. They had to collaborate with the process engineering and procurement group. Budget Segment Owners were the champions of the commodity cost reduction program.

Commodity Cost Meeting- CCM

Budget Segment Owners were linked through the Commodity Cost Meeting (CCM) group, who were the virtual management team for commodity cost. The CCM collaborated with the different plants associated with the same product to encourage consistency and shared knowledge between facilities. It was part of the "Copy Exactly" processes and systems. They established the process of how to manage commodity cost at the virtual factory for fabrication plant comparisons.

Engineering Module Teams

There were more than twenty engineering module teams defined by a tool family. A tool was an equipment used on a specific process step(s), such as the Sputtering Tool, which was used for the Sputtering Process Step. Each engineering module team would manage a set of the same equipment brand, which was described as a tool family. Within these engineering module teams, the process engineers and equipment engineers collaborated profusely on process improvements. They had virtual factory roadmaps for process improvements. By comparing yield and output between plants for best-in-class comparison, they realigned any significant differences from plant to plant. These measurements, best- in- class and worst- in- class comparison, further enforced the principles of "Copy Exactly."

Module Team Coordination Meeting –MTCM

The twenty or more engineering module teams at Fabrication Plant-7 were linked through the Module Team Coordination Meeting group, who met on a weekly basis to discuss the plant's overall weekly objectives. They were more focused on the day to day and weekly plant specific issues. Because of their size, they were segmented into four groups defined by family process. For example, all the process equipments involved in lithography formed one MTCM. They were incentivized and accountable for output, yields, and ensuring a safe environment.

Engineering Coordination Meeting – ECM

The MTCM collaborated with the Engineering Coordination Meeting group, who were the virtual process engineering management team across the fabrication plants. They provide the higher-level direction of process improvements across the fabrication plants.

Ramp Program Managers (Meeting)- RPM

The Ramp Program Managers are the plant managers associated with the same product line. They form the virtual factory steering board. The rest of the internal and external groups aligned to their direction and vision.

Engineering Cost Champions

As a result of the cost reduction initiative, each engineering tool family had a committed cost champion that enabled the cost coordination and management at the process engineering level. The cost champions coordinated between the MTCM, engineering module teams and the Budget Segment Owners. They were crucial to engaging the rest of the virtual factory and spreading the process and systems of the cost reduction program. They were incentivized based on the ensuring safety, quality and output.

2.2 Political Structure: Who had influence?

Coordinating within this virtual organization was challenging, because of the multiple groups involved. An individual had to coordinate within their plant and through the virtual plant to get buy-in on decisions or proposals. Knowing the positive and negative polarity of influence was quite important to make any advancement in this organization. Obviously, to make any change at Intel, the virtual factory had to concur.

Therefore, the Intel environment had multiple collaboration teams that met periodically to help coordinate the efforts. It was a huge matrix organization, where buy-ins can expand across regional locations and at different levels within the organization. Any organization within the matrix that was part of a virtual factory team had a large positive influence on the multiple fabrication plants. The decisions were made by the virtual factory teams and then proliferated down and up into the organization and fabrication plants.

In cost management, the RPM **set the direction** for the plants. They were the plant managers within the virtual factory that had the highest position within the plant organization. Normally, a plant manager has great autonomy within their organization, but at Intel, more collaboration between like peers was the norm. It enabled the "Copy Exactly" manufacturing principles. In general, they were aligned to the incentives that kept the plant in production at high yields with record speed to market.

The next influential group was the ECM. They had direct authority on making decisions about the engineering roadmaps in the virtual factory. Therefore, if a project was not listed on the roadmap, it was not being worked on. The ECM was the execution or implementation arm of the virtual organization. The ECM **delivered** against the plans or process changes that impacted the operation and production of manufactured microprocessors. As a virtual team, they linked themselves back to their individual plant through the MTCM for ease of collaboration. Performance of this group was based on flawless execution of process improvements and support of product introduction into manufacturing.

The third influential group was the CCM. They collaborated amongst the Budget Segment Owners in this virtual factory. They set the normalized target for commodity consumption for each plant based on historical data, benchmarked data and affordability. Within this group, they **provide the process** on how to measure commodity cost performance for each commodity within the fabrication plants. It was essential that from plant to plant, the accounting processes were similar and validated. If the calculations were not based on the same assumptions and calculations, the plants could not be compared on best- in- cost performance. Best- in- cost performance enforced the "Copy Exactly" operating principle. They ensured healthy balance on cost metrics. The CCM performance was aligned to meeting cost targets within and across the plants.

If the cost reduction program had any chance of success, the RPM, ECM and CCM had to buy into the program. Each group had a different role of influence into the success of any process changes in cost management. The following table, Fig. 2.2-1, provides an overview of the status of each group prior to the implementation of the cost reduction program and what stage they had to be in order to implement the cost reduction program.

Fig. 2.2-1. Political Commitment Chart

Key Groups	No Commitment	Let It Happen	Help It Happen	Make It happen
RPM			● →	→ ☺
ECM		● →	→	→ ☺
CCM			● →	→ ☺

Note:
- ☺ Represent where they need to be in this Commitment/Influence Chart
- ● Represent where they are at the Initial Stage of the program

Within these groups, there were vital individuals that can influence the direction of the group. It was helpful to sense the commitment level of individuals within these organizational teams. The committed individuals that had a direct power of influence served as a conduit to support progression. During the final weeks of the six months of the internship, the RPM, CCM, ECM were edging towards the happy medium. In contrast, Fabrication Plant-7's plant manager, engineering managers and Budget Segment Owners were committed and completely engaged in the cost reduction program at the onset.

Besides establishing the roadmap of the influential and committed parties within the organization, the communication of the plan was equivocally important to other non-influential groups. The non-influential groups were entwined into this virtual matrix network with their own objectives to Intel's overall performance. They had exogenous goals and objectives to the cost reduction program that could be beneficial or detrimental to the overall progress of the program. By communicating the plan, the fear of the unknown diminished and credibility increased. The following diagram describes the roadmap for communication during the cost reduction program.

Fig 2.2-2 Communication Roadmap

The top row indicates all the working groups within the facility and throughout the virtual factory that are entwined with cost management. The left column indicates the different levels of performance measures and processes in place for the cost reduction program. By color coding the matrix red, yellow and green indicated the level of information transferred. Red indicates no transfer. Yellow indicates some knowledge. Green indicates complete transfer and mentioned as part of their periodic reporting. The blank spots indicate no transfer needed. The group names within the matrix indicate who will transfer the information.

Communication Cost Matrix

	CCM	RPM	ECM	BSO	MTCM	Engr Cost Champion	Fabrication Plant-7 Plant Mgr	Fabrication Plant-7 Engr. Mgr
Cost Management Plan	BSO	CCM	CCM					
MTCM Performance Indicator								
Summary Report-Report Card					BSO	BSO	BSO	BSO
Virtual Factory Cost Performance		CCM			CCM	ECM	CCM	CCM
Module Cost Tracking								

The virtual factory teams were a major player (RPM, ECM, and CCM) in this organization. It was also important to get buy-in from the engineering group that would be directly involved in cost management. The continual communication and education of the engineers were essential to decrease fears of the unknown responsibilities and challenges.

2.3 The Strategy

2.3.1. Introduction

Discerning between the influential and the commitment level within the organization facilitated the groundwork to seek information. It helped evaluate whether the overall strategy of cost reduction was perceived as rational and a purposeful program. There were two major reasons why this program was purposeful. One reason was the ability to increase cost savings within the product life cycle. The other reason was the transfer of cost ownership to a group or individuals that can have the greatest impact on commodity costs, the process-engineering group. These reasons are linked to two of the concepts in reengineering (or "thinking lean") as defined by Michael Hammer. This section will explore the concepts of reengineering and how reengineering impacts the cost reduction program. It will also describe the strategy of cost management prior to the implementation of this program.

2.3.2. Cost Management Strategy: Before

Cost reduction was not a focus during production ramp, which was the initial stage of the product life cycle in manufacturing. Cost was not a competitive advantage for Intel, but a by-product of technology advancements. From Moore's law the relative cost of manufacturing a component decreased relative to the number of transistors per component. Moore's Law delivered more processing power at the same price to customers, a technical advantage for Intel. With the same price, the demand remained the same or increased for more processing power. Intel had a dominant power in this industry with 80% market share. Manufacturing had to meet the demand by ensuring the quality and output of the product. Cost reductions were applied later in the manufacturing product life cycle, during the sustainability stage.

The Budget Segment Owners (BSO) were accountable for the commodity consumption management, including the reduction of commodity consumption. The budget segment leaders were organized according to specific commodities, but had no direct impact on cost reduction projects on the commodity consumption at the plant floor. However, they had some influence on advancing cost reduction projects at the plant floor. They reported weekly cost performance activities and accounted for the cost performance. Through collaboration with other groups, they initiated most of the cost reduction projects to meet the fabrication plants' quarterly commodity goals.

This process changed by applying reengineering concepts to the cost management process. The reengineering concepts of "who does the work" and "when does the work happen" drove the redesign of the cost management structure at Fabrication Plant-7.

2.3.3. What is Reengineering?

What is reengineering? Reengineering, as defined by Michael Hammer in the book, The Reengineering Revolution, is "the fundamental rethinking and radical redesign of business processes to bring about dramatic improvements in performance."

When reengineering was initially introduced to companies in the early 1990's, the word reengineering was a common vernacular to many companies. They used the word to describe the following: redeployment of their people, company downsizing, reorganization, etc, without addressing the business processes' productivity. The meaning and the purpose of reengineering were completely misconstrued. Several books by Michael Hammer, like The Reengineering Revolution, provide the essential concepts to understanding reengineering. The bibliography in this thesis lists additional works by Michael Hammer that address in detail the concepts of reengineering. The ideas and examples cited in this thesis have been expressed by Michael Hammer lectures and books.

There are six important concepts that underlie reengineering the business process. Before divulging the main concepts, let's address the **business process** classification, which is fundamental to understanding reengineering. A business process describes the end-to-end work to the **customer**. Essentially, it has an input from the customer that leads to an output to the customer. For example, order fulfillment is an example of a business process. It starts with an input from the customer, a requisition order, to an output of product delivery to the customer. If the work is not end-to-end to the customer, then it is not classified as a business process, but as a task or procedure used in a process. Now the main concepts to redesigning a business process are the following:

1) Who does the work,
2) When is the work done,
3) Where is the work done - location,

4) Whether the work adds value,
5) How intense should the work be,
6) And keeping it simple.

In order to explain some of these concepts, let's review a general process that needs redesigning, like a customer support service process. A customer has a technical problem with a product and calls for customer support, the input. To satisfy this customer, a positive process outcome would be a resolution to the problem over the phone or an indication on when the problem would be resolved. However, in this situation, the customer representative records the problem and does not indicate how and when it will resolve the customer's problem. At this point, the customer is frustrated. The customer representative provides the information and data to the service technician. The technician attempts to identify the problem by applying a systematic troubleshooting method. The technician narrows the possible problems and solutions, but sends the information to a central field support center. The central field support center identifies field technicians available to support the customer and calls the customer representative with the information. The customer receives a call back with information about timing for the support. The field technician proceeds to the whereabouts of the customer and resolves the problem. At this point, the customer is less frustrated, but it took five days and four people to address this problem. How can we redesign the process?

First, we can redesign the work so that the field technician and the customer representative act as one individual. The customer representative can enter the information into a database that will automatically identify the potential problems. This redesign identifies **who does the work** concept. By getting rid of the call back process to the customer and using a technician resource database to assign a field technician during the initial call with the customer adds a great deal of value. The customer receives the information of when the problem will be resolved. In addition, this redesign includes the concept of **keeping it simple, when the work is done** and **whether the work adds value.**

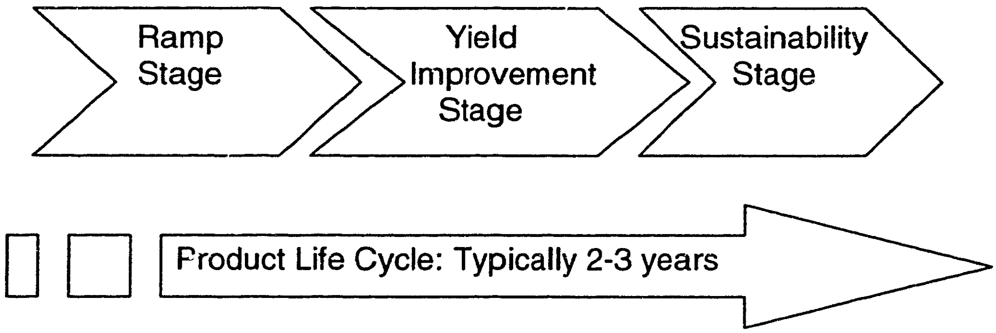
For the most part, these are concepts that facilitate the redesigning of the process. As far as the cost reduction program, Intel attempts to reengineer the cost management process by focusing on two important areas, "who does the work" and "when is the work done". The concept of "keeping it simple" was added during the execution of the process.

2.3.4. When: Product Life Cycle

Intel wants to introduce cost reduction efforts during ramp, which increases profit gains during the life of the product. By pushing the barriers of Moore's Law, Intel aggressively pushes the product life cycle in the market every two to three years. With a fast product life cycle or clock speed, the product will enter the market, reap as much revenue and profit as possible, before it obsolesces. In the beginning of the product life, most manufacturers tend to break-even, until they reap the benefits from the learning curve. However, with a fast clock speed product, it does not allow a great deal of room for reaping the learning benefits.

Therefore, pushing cost savings further upstream, at the ramp stage (Fig. 2.3.4-1. the stages of product life cycle), provides an increasing cost savings for the life of the product. It clearly addresses reengineering "the when" of the cost management process. Although this strategy is purposeful, the cost savings program is a challenge because it does not align to the current manufacturing and core-operating principles: safety, quality improvement and output.

Fig. 2.3.4-1: Product Life Cycle



Further, the implementation of this strategy at Fabrication Plant-7 initiates a plethora of cost reduction projects into the process. However, the "Copy Exactly" concepts delay these projects due to the rigor and the check and balances involved. For the most part, focusing on cost reduction during the ramp rather than at the sustainability stage is reengineering "when work happens" in the cost management process.

2.3.5. Who: Process Engineering owns Cost

Another major challenge through the efforts of the redesign was who would ultimately be responsible for commodity cost reduction. In the current process, Budget

Segment Owners (BSO), who was part of the Manufacturing Systems Group, owned commodity consumption budget. However, they had no direct influence on reducing consumption at the plant floor, so they partnered with the procurement group and the process-engineering group to reduce cost. Through their initiatives and persuasiveness, they strategically identified and implemented high potential cost saving projects that met their budget goals, year after year.

However, with this new cost strategy, the process engineers that were so focused on the speed of ramping to a product line with high yields have to include cost saving opportunities without any additional resources. This is redesigning the cost management within the manufacturing organization at Intel. By moving this responsibility to the process-engineering group, the process engineers control cost expenditures and make a direct impact on cost savings on the plant floor. According to Michael Hammer reengineering concepts, it addresses "who does the work" in reengineering a process. The process-engineering group would have all the capabilities to effectively manage commodity cost without additional layers of coordination, which would add communication gaps and longer lead times. The process engineers' work adds value and is necessary for commodity cost management.

2.4 What is Intel's Culture?

2.4.1 Introduction

Organizations define their culture by aligning their values, operating principles and operating objectives to their incentives, like monetary wage or promotions. This has been a strategy for many organizations as they ingrain the culture that increases their competitive advantage. The following theory is based on Sloan's Strategy and Organization course lecture notes by R.Gibbons, titled: Agency Theory: Pay for Performance and Getting What You Pay For. Therefore, in the case of a monetary wage, an employee is compensated by a base salary and bonus. The base salary is based on the skills of the position and the bonus is based on the culture the company attempts to define and their financial gains. In theory, any achievements that enable the operating objectives by utilizing the values and operating principles were highly rewarded.

Bonus = Values (as %)*Operating Principles (as %)* Financial Gain Objectives.

The different values and operating principles were expressed as percentages.

The values and operating principles are the company's organizational competitive edge. It creates the cultural behavior of the organization to maintain their competitive advantages.

For Intel manufacturing facility, the operating objectives were **safety, quality, and output** associated to some financial gain. The bonus consisted of stock options based on individual performance and cash payouts based on company's financial gains, division performance and individual performance. During high growth period, the stock options were very lucrative and a high monetary incentive to Intel employees. Since values and operating principles had an impact on individual bonuses, these were ingrained into the organizational culture. Intel had the following company values:

- Customer Focused,
- Disciplined,
- Quality,
- Risk –Taker,
- Great Place to Work,
- Results-oriented.

The operating principles at Intel were very strong indicators of Intel's culture, which included "Copy Exactly" and "rewarding by meritocracy". In this section, we will discuss how the commodity cost reduction initiative depends on Intel's current culture as characterized by their current values, operating principles, three main objectives and numerous interviews within Intel's value chain organization. We will evaluate how the values, operating principles and three main objectives affect the overall implementation of commodity cost reduction initiative. In addition, this section will provide some insights to the Fabrication Plant-7's culture, which was slightly different from the rest of Intel.

2.4.2 Is cost aligned to Intel's core objectives?

The manufacturing Fabrication Plant-7 has three core operating objectives: safety, quality and output. All three can have a direct negative impact on commodity cost savings. The mindset was to achieve all three objectives and not to consider cost effective solutions until a product line was producing high quality yields in a safe environment. These objectives address the essential issues in order to successfully manufacture high volume, but the objectives increase waste and cost consumption in the manufacturing environment. The culture was not receptive to any cost reduction initiatives, especially at the onset of ramping production. While increasing output and quality without cost considerations was an acceptable culture during the upturn of the economy with high margins and high demands, it was a painful experience during the downturn of the economy. With lower demands and margins in this economy downturn, maintaining a lean business was crucial for survival.

SAFETY

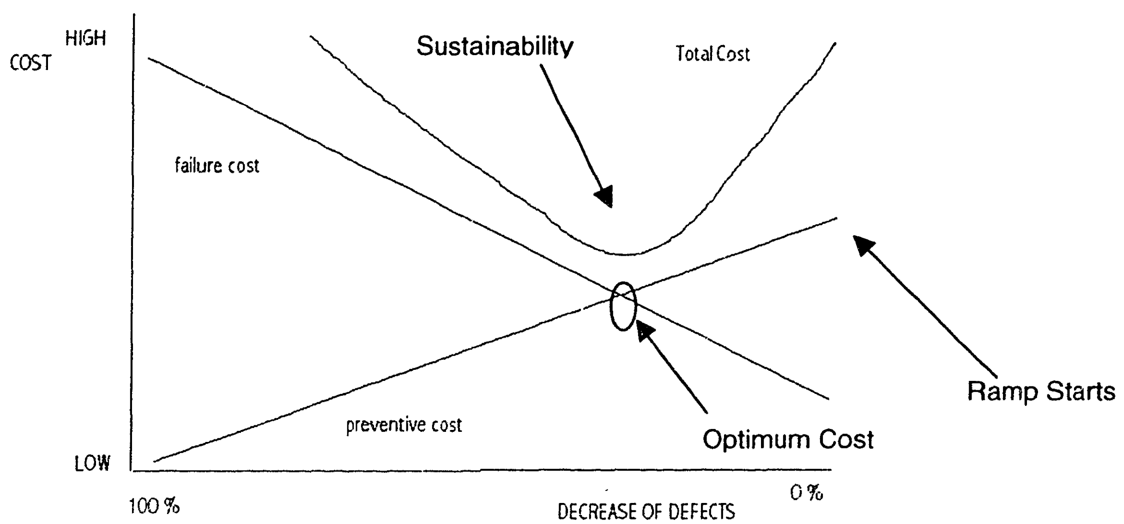
Being safe is not only an objective at the manufacturing facility, but a culture within all of Intel. It was evident by the norms of groups addressing safety issues at the beginning of every meeting, including cost meetings. The mindset of process engineers and manufacturing technicians were focused on safety first, then quality and output. As safety events and actions increased, the cost increased as well. However, Intel would not compromise this objective. With the focus on cost during ramping stage, safety was the last area to search for cost effective solutions.

QUALITY AND OUTPUT

Intel relentlessly engaged in preventative measures to assure lower defects and reduce cost of failures on their products. Preventative measure costs include any inspection done during the production process and any proactive quality processes put in place that prevent the release of failed parts to the customer. Studies by American

Society for Quality, prove that preventative measures of quality prevent yield losses and increases output. Intel wants to minimize any failure costs, if possible, in the production of microprocessors. The failure costs are the monetary values associated to quality problems, like return of failed parts, lost of vendors, reworks and downtimes. Failure costs reduce overall output, decrease yield, decrease revenues and reduce potential revenues in the future. Intel began ramp production with conservative preventative measures to minimize the failure cost at the onset. As a fictitious example, if 10 ml of slurry was proven from past historical data to be an effective processing parameter, 10 gallons were used to be on the safe side. Nevertheless, with the learning curve, Intel tends to move towards an optimum cost target during the sustainability stage. In Fig. 2.4.2-1, a graph of cost of quality indicates the optimum cost area.

Fig. 2.4.2-1 Cost of Quality Graph



Thinking "lean" is a challenge to this culture and an obstacle to overcome for the cost reduction program. Engineers felt that they had too much to balance on their plate during production ramp, if they included cost into the equation. Not having enough time to manage cost efficient solutions was a major concern. Management from the virtual factory (RPM) knew that cost reduction was an inevitable new direction with the economic downturn, expectations of lower price from customers and competition from other microprocessor manufacturers. Fabrication Plant-7 management was committed and took the lead by aligning their objectives to include cost. At Fabrication Plant-7, the core objectives changed to the following: safety, quality, and **cost-effective** *output.* By including the objective of cost-effective output at the Fabrication Plant-7, engineers settled into taking the challenge to achieve cost reduction savings during production ramp.

2.4.3 Is "Copy Exactly" aligned to cost reduction initiatives?

As stated before, "Copy Exactly" is the manufacturing principle that enables Intel to transfer new technologies from development to manufacturing successfully at record speeds. In addition, it involves the intense collaboration of multiple manufacturing facilities across the world to maintain the exact process parameters and procedures for high volume manufacturing. For further analysis and details on "Copy Exactly", refer to the following MIT theses by: Fears '94, Florey '97 and Mlynarczyk '95. While this operating principle offers benefits in achieving Intel's overall objectives, it sometimes can encumber process changes.

Benefits of "Copy Exactly"

Because of "Copy Exactly", the virtual factory had measurements for comparing each fabrication plant in regards to the three objectives. The performance measurements of best –in- class (BIC) and worst –in –class (WIC) **encourage competition** amongst the plants. By comparing themselves to the commodity cost measurements across plants, it further enforced "Copy Exactly" operating principle and culture. If a fabrication plant was performing worst –in –class, it will search for the differences that prevent it from realizing the average commodity cost consumption as the other plants.

With "Copy Exactly", after a decision has been made in the virtual factory, the implementation diffuses into the different facilities. The virtual meetings with the essential stakeholders at the different facilities were responsible for implementing the plan at their facility. This principle **facilitated the proliferation** of the cost reduction program throughout the virtual factory.

With a fast clock speed product, "Copy Exactly" **helps to manage the chaos** in this type of industry. "Copy Exactly" **inculcates rigor and discipline** into the organization. This was highly effective for a highly complex manufacturing process, which needs a high degree of **attention to details**.

Disadvantages of "Copy Exactly"

Because of the cross –regional groups involved in the decision making process, the **coordination costs were high**. Virtual team meetings involved multiple people on conference phones, rather than a face to face meeting in an enclosed room at the plant.

As management commits to this new challenge on cost reduction, the process to move forward was **prolonged**, because of the collaboration efforts across the fabrication plants. The projects were delayed, because of the necessary buy-ins from each of the fabrication plants' representatives. Every manufacturing process **decision was centralized** to a virtual factory team, which met periodically. The virtual factory team had to meet at times convenient to each region zones.

"Copy-exactly" **reduced any decentralization or autonomy** within the organization. It **reduced the sense of urgency**. Although it instilled a necessary sense of rigor in the organization, the effectiveness of the rigor can be construed as a non-value added characteristic of "Copy Exactly". For example, a process change control undergoes multiple reviews by different sub teams across the virtual factory and the plant. With this level of coordination and collaboration, the end-user and owner of the change control may perceive at times the rigor is not necessary, while others perceive it as valuable check and balance process.

2.4.4 Do Intel's values benefit cost reduction?

A company's values attempt to define the culture of the organization, thereby the behavior of the employees. **Discipline, results-oriented, quality and a great place to work** were four out of the six values that were highly visible characteristics in Intel's culture based on observations at the Fabrication Plant-7 and interviews from LFM colleagues. These values play a major role in enforcing the behaviors of "Copy Exactly" and advancing the concepts of Moore's Law while managing Intel's meritocracy environment.

For example, discipline and quality encouraged a culture that followed the "Copy Exactly" principles, because of the numerous checks and balances involved. Additionally, discipline and quality ensured safety, and quality output from the fabrication plants. Discipline and adhering to quality were important values to Intel's overall strategy of manufacturing high volume and reliable products.

At the end of the day, everything was based on results, whether it was a new product development utilizing the concepts of Moore's law or the successful execution of a fulfillment order to a customer. By being results- oriented, the culture developed a meritocracy system, where individuals were rewarded based on their talents and achievements. It was a competitive environment, where individuals compete against each other through the "ranking and rating" performance process. Employees with the same grade level were ranked and rated amongst themselves based on their achievements. In addition, the plants competed within the virtual factory using best-in-class metric comparison systems.

A "great place to work" as a value is more of an outcome than a tangible value. It does not describe the types of behavior within the organization, but the ultimate objective for employees at Intel. Intel stressed work life balance and retained employees through their perks and incentive structure. Intel employees were involved in multiple community activities to help balance work and life. In addition, telecommuting was made available to most of Intel's employees to encourage a work life balance. The dress code at Intel was extremely casual, where individuals were allowed to wear shorts to work. With perks and an attractive incentive system linked to Intel's stock, Intel retained its employees, thereby retaining their knowledge base within the organization.

From interviews with the LFM Intel community and the interaction of different functional groups at Fabrication Plant-7, not all of Intel's values were visible in their culture. The perception was that internal customer-orientation and risk-taking values were a challenge for some groups within the organization, because occasionally it conflicted with other objectives, values and the operating principles of Intel.

Risk-taking initiatives allow more innovation and out of the box thinking. It is a value that is necessary, if Intel wants to produce the next grand invention or continuously improve their current products. Nonetheless, it staggers at times within some groups because of the rigor and core rigidity principles ingrained in this fast product clock speed company. For example, some of the cost reduction projects in manufacturing were discarded before any validation testing, because of some perceived level of risk. These discarded cost reduction projects were validated in past products as major successes, but some of the engineers were not willing to take the risk. Intel's manufacturing objectives were still aligned to ensuring the quality and the output of the product, rather than cost effective solutions. There lies the conflict. However, the technology development group and research group exercised risk through their work, which will be discussed later in this thesis.

Focusing on the internal **customer** was a challenge for some of the groups within the organization. For example, the engineering group worked with the Budget Segment Owners on reducing commodity cost at the plant. However, both spent most of their times at meetings placing blame on target errors and overspending issues. At the same time, the Budget Segment Owners supported the engineer's cost awareness and educational efforts and the engineering group provided insights on potential cost reductions. The emphasis in this relationship should have been on education, shared learnings and seeking additional cost opportunities as their ultimate goal of reducing cost. In retrospect, most of the focus was placed on ensuring the metrics were aligned to meet the goals, by any means necessary. reductions.

The values, results-oriented, rigor, and enabling did not pose a threat to the cost reduction initiatives. These values provide the right culture to maintain the current processes and facilitate any new process change. However, customer-focused and risk –taking was a challenge for the manufacturing culture. These two values would enable the cost reduction initiative.

2.4.5 Fabrication Plant-7 Culture

Fabrication Plant-7 emulates the thoughts of Andrew Grove, "only the paranoid survive". Fabrication Plant-7 organization competed fervently to be BIC(Best-in- class) in yields, output and now cost. The employees at Fabrication Plant-7 behaved as if they were in "survival mode" and always had to prove their existence within Intel's portfolio.

It was easier to integrate any new challenges into this facility, because of their need for continual wins and acceptance by Intel Technology Manufacturing Management.

In retrospect, Intel Fabrication Plant-7's culture enabled the cost reduction program, after the cost objectives were aligned to *cost-effective output.* Having commitment from the management level was an important factor to the successful implementation of the program at Fabrication Plant-7. They seized the challenge, because "only the paranoid survive." Although the proliferation of the program lagged for the virtual factory, because of the intense collaboration involved in decision-making and knowledge sharing, Fabrication Plant-7's competitive nature drove the virtual factory to integrate and adopt their systems and process for the cost reduction program.

In summary of cultural and organizational analysis, the integration of cost reduction was not simple, but there were some key factors in the culture that posed a threat and enabled the cost reduction program. The manufacturing objectives of quality and output posed a threat, but it was balanced when Fabrication Plant-7's management added cost-effective output. "Copy Exactly", a valuable operating principle to Intel's manufacturing success, delayed the cost reduction program, but enabled the proliferation of the cost reduction systems into the virtual factory. The cost reduction strategy was purposeful and achieved high cost savings by integrating those that would make the greatest impact.

3 Cost Reduction Program and the Change

3.1 Introduction

As the cost reduction program came into effect at Fabrication Plant-7, a few tangible factors integrated the program into the process-engineering group. As mentioned before, the type of culture at Fabrication Plant-7 was ready for any challenge. However, any prior apprehension from process engineering was due to a lack of information and the credibility of the program. No one wants to buy-in, until there is a sense of security and understanding of the process. With that came three important dynamics to the successful implementation: education and communication, creating a vision and making work simple.

3.2 Educating and Communicating for Change

In a time of change in an organization, most are fearful of the unknown. The unknown leads to a defensive and sometimes distrustful behavior. The process-engineering group at Fabrication Plant-7 was apprehensive about the cost reduction program at the beginning. They thought that cost reduction was not necessary now and would decrease the yield and output of the line. The engineers worked fervently to obtain best-in-class (BIC) in quality and output within the virtual factory. Jeopardizing this position was unacceptable, since the engineers were accountable for ensuring the product line quality and output, not cost.

Therefore, the Budget Segment Owners for each commodity at Fabrication Plant-7 engaged the process-engineering group by first introducing them to the importance of cost reduction for the overall company. They used clear situational examples and measurement charts with reference to BIC cost performance for the virtual factory. The Budget Segment Owners communicated the plan and process throughout the different levels within the organization, from the management level to the operators on the plant floor. The objective was to reduce the apprehension and the resistance through education and awareness.

The Budget Segment Owners educated the process-engineering group about the current systems in place that will help them understand their top spending consumption. This was highly beneficial, since the information established the areas that they should target. As the Budget Segment Owners became more aware and empowered to manage their actual consumption spending, they became more conscious of unnecessary spending, spending errors, and potential cost reduction projects. The awareness of cost expenditures led to a new behavior that realized short term cost savings based on eliminating waste and quality errors within the enterprise resource planning (ERP) system.

3.3 Creating a Vision

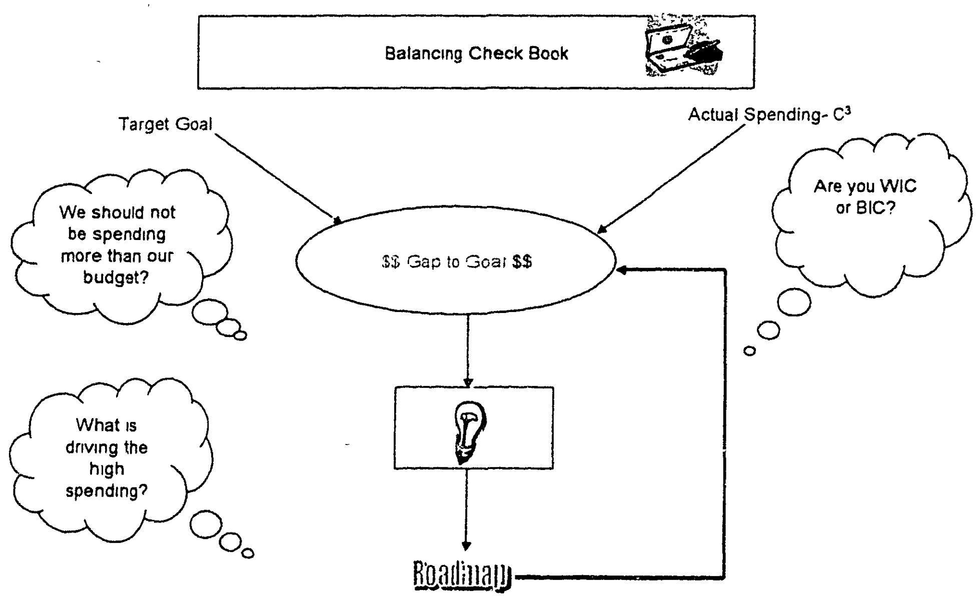
Besides educating and communicating, creating and understanding the vision were a crucial part of successfully implementing this cost reduction program. The vision helped the process engineers visualize the end goal of the program. The vision of this program was to produce cost-effective product at high quality. Focusing and planning on a consistent vision were vital in reducing ambiguity and increasing credibility.

Ownership was transferred from Budget Segment Owners to the process-engineering group, who made a direct impact to commodity cost consumption on the manufacturing plant floor at Fabrication Plant-7. In addition, the cost management program would have to be a part of Intel's process at the onset of the manufacturing product life cycle.

3.3.1 The Metaphor: Balancing the Checkbook

The metaphor of **balancing a checkbook** was used to provide a clear and simple message on how to manage cost (Fig. 3.2.1-1. the figure of balancing checkbook).

Fig. 3.3.1-1 Balancing checkbook concept:
The targets were published and agreed upon. The gap to the target goal for each area was determined. Possible cost reductions ideas were placed on the roadmap to narrow the gap-to-goal. A projected gap-to-goal was determined based on the current spending rate. If spending rate was high and caused a negative gap-to-goal, then new projects were placed on roadmap to adjust gap-to-goal. If the gap-to-goal was positive, the information was used to help monitor and present achievements. As balancing a checkbook, this was a continuous process.



Each tool area was allotted a certain amount of budget target each week based on amount of wafer output, the credit. Every week the actual spending consumption was compared to the weekly budget target- a forecasted value based on historical consumption, affordability, benchmarked data and weekly output. If the difference was a positive value, the tool area's spending consumption rate was according to their allotted budget. However, if the difference was a negative value, the tool area was spending more than the allotted amount. The negative value denotes the idea of writing a bad check for that week. The tool area would attempt to understand the reason behind the high consumption spending of commodities for that week.

Sometimes, the tool area had quality issues for that week and needed additional parts, chemicals, and/or wafer inspection. This is similar to an emergency budget fund. If spending was above the allotted budget for that week, then reductions of cost expenditures were made for the following weeks. For example, if a tool (equipment) was down, engineers performed multiple PM checks to resolve the downtime issue in the hopes that one of the checks would resolve the problem. However, some of those PM checks were not necessary and became too frequent. Can the troubleshooting method become more robust to eliminate unnecessary PM checks? Eventually, with learning over time, some of the quality issues would be resolved. Ultimately, the idea was to spend on what was allotted based on planned objectives, like PMs, rather than spending on unplanned PMs. It cultivated a cost conscious culture. It brought visibility to the direct dollar impact associated with resolving a quality issue. Therefore, the thought was how to resolve the quality issue faster and cheaper. It provided a new perspective to the immediate impact of quality problems in terms of commodity cost.

If the gap-to-goal was a negative value on a weekly basis versus a one-time event, long term cost reduction projects were needed. The cost reduction projects would address PM reductions, process step elimination, or elimination of inspections. Intel manufacturing line consisted of plethora of inspection steps. The inspection process steps were part of the quality preventative measures. These inspection steps were considered a NVA (non-value added) work. They were necessary, but added no direct value to the output of the product.

The metaphor of balancing a checkbook is similar to another concept of cost reduction at one of Intel's fabrication plant. They used a "shopping list" metaphor to enforce process cost discipline. Spend what's on the list and no more. Process engineers at Fabrication Plant-7 used the analogy of balancing a checkbook to ingrain the continual process of cost reduction into the environment. The concept further ingrained a behavior of being detailed, disciplined and aware of cost expenditures with periodic checks as in managing a checkbook. Knowing that discipline and rigor was part of Intel's value system and culture facilitated the vision of "balancing the checkbook".

3.4 Automated Cost Systems

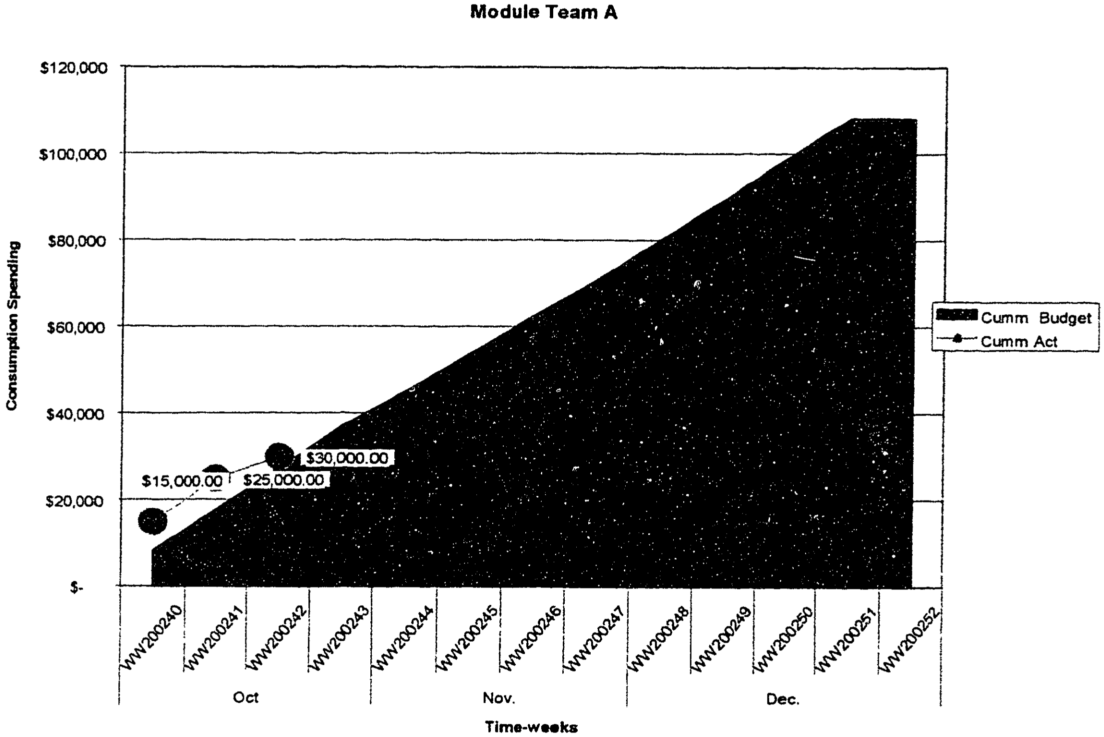
After establishing the process and creating a vision for further process improvements, automation played a significant role in engaging the community faster rather than later. In the cost reduction program, two database systems had a major contribution to the impact of change. One was a cost management system that detailed cost transactions down to the tool family area through a web-based system. The systems enabled the entire virtual factory to review cost expenditures for Intel in commodity consumption. The other online database tracked cost reduction projects in the virtual factory. Both systems extracted data from other databases at Intel and placed it in one central area. Each database contained a vast amount of information; therefore, the need to consolidate and transfer the data into real information was necessary. In this section, the consolidation process of these databases for effective use will be discussed.

3.4.1 Cost Champion Tracking Systems

For each of the tool areas, commodity cost consumption was an issue. Each tool area had a cost champion that was engaged in reducing cost for their area. Ultimately, the vision was cost ownership at the process engineering level. Therefore, they each managed their own performance charts (Fig. 3.3.1-1 Cost Commodity Tracking chart for a tool area) that contained weekly updated information about their gap-to-goal progress. The consolidated tracking systems automatically extracted the budget target data based on each tool area. Then, the engineering cost champions reviewed the charts on a weekly basis to obtain their progress with cost reductions and gap-to-goal data.

Fig.3.4.1-1 Cost Commodity Tracking Chart

The tracking sheets provided the cumulative cost expenditure for the quarter based on planned output, the triangular shape. The actual cumulative actual expenditures were updated across the chart weekly, the line graph.



In addition, the engineering cost champions had a roadmap template to track the status of projects and projected gap-to-goal for the quarter based on the average spending for the quarter. The roadmap adjusted automatically based on the spending rate for the quarter. It was a tool to help the engineering cost champions communicate their current gap-to-goal with information about active and on-hold cost reduction projects. This system was user friendly and was linked to the other systems for consistency.

Fig. 3.4.1-2. Roadmap of Commodity Cost Tracking

The Cost Gap Goal was the cumulative gap-to-goal for the quarter based on the current spending rate. The active projects for the quarter were added as potential cost savings that would narrow the gap. In this example, the module team had a $100K negative gap-to-goal for quarter 3. The two active projects had a total savings of $80K for the quarter, which would narrow their gap-to-goal to a negative $20K. In addition, on-hold projects would help them close their gap-to-goal further, by placing them on the positive side of $10K.

Gap Closing Roadmap for Module Team A

	Q3'02($/Qtr)	Q4'02($/Qtr)
Cost Gap Goal:	$ (100,000)	$ (200,000)

ACTIVE Projects

ID	Project Name	Project Owner	Q3'02($/Qtr)	Q4'02($/Qtr)	ECD	Start Date	Duration
	Project 1	Me	$ 30,000	$ 50,000	2002.35		
	Project 2	Me	$ 50,000	$ 10,000	2002.35		

SPARES	Q3'02	Q4'02
Savings $	$ 80,000	$ 60,000
Remaining Gap $ (Negative # indicates gap)	$ (20,000)	$ (140,000)

HOLD Projects

ID	Project Name	Project Owner	Q3'02($/Qtr)	Q4'02($/Qtr)	ECD	Start Date	Duration
	Project A	Me	$ 30,000.00	$ 60,000.00	2002.3		
	Project B	Me					

SPARES	Q3'02	Q4'02
Total Savings $	$ 30,000	$ 60,000
Remaining Gap $	$ 10,000	$ (80,000)

By having cost champions report and manage their own tool area for cost performance, the cost champions were able to appreciate the cost reduction program. The total timing for data gathering was fifteen minutes a week, which left more time for the cost champions for each engineering module team to manage project implementation. The reliability, ease of use and flexibility of the systems built the trust and credibility of the cost management program. The cost champions became more accountable for the information and applied their knowledge about commodity consumption on the plant floor to validate the numbers reported on the database. Eventually, the cost champions were empowered to manage cost in their tool area, which cultivated a cost conscious behavior.

3.4.2 Consolidating More Systems

Since each tool area was part of a specific engineering family group, there was a need to consolidate the performance for each of the four engineering groups and the entire fabrication plant. For example, there were six-tool families representing Thin Films, and another six for Etch, and so on. Therefore, each engineering group had an overall performance indicator consolidated from each of the six or five tool areas, automatically. The consolidated data provided management with a summary of performance of the facility as whole, for each of the four engineering family groups down to the module tool area. The automated summary sheet was effective in engaging the management team at Fabrication Plant-7 into the cost reduction program. For confidentiality purposes, it is not illustrated in the thesis.

Overall, the systems provided a sense of ownership at the engineering level. The systems were implemented through the MS Excel, because of its familiarity and scalability into SQL database system.

4 Next Generation Automated System

4.1 Introduction

With much success in the automated systems, the engineers had information at their fingertips, which helped them manage cost. The use of the databases empowered and cultivated a cost conscious culture. This section describes an automated system that was used to further facilitate cost conscious behavior. The system determined the expected consumption for spare parts based on white papers, procedures, and PMs. Currently, the forecast of consumption of spare parts was based on historical data on parts pulled from stock, which is different from actual consumption on the plant floor. The Budget Segment Owners used the historical consumption data based on parts pulled from stock to forecast the targets. However, the frequency of parts used on PMs based on procedures and process provide a better representative of the theoretical consumption of spare parts. Therefore, this system would provide the visibility of the "theoretical" consumption value of spare parts based on PM frequency to help drive discipline of reducing plant floor spare part inventory. The technicians on the plant floor would only pull parts that were needed, instead of storing extra parts on the plant floor that were not tracked by any database.

The test wafer, gas, and chemical commodity area had a database and management system that assessed expected consumption based on current process procedures. The visibility of the expected consumption based on process procedure for spare parts would be a tremendous win for cost reduction initiatives. It would provide automatic and up-to-date performance metrics on the adherence to cost discipline on the plant floor. A prototype system named Spares Theoretical Bottoms Up Estimation (BUE) was designed to compare actual consumption of spare parts, based on consumption of parts pull from stock, to forecast consumption based on PM schedule.

4.2 Development of Automated Spares BUE

Due to confidentiality, some of development stages will be kept broad in this section. First step in the development was defining the objective and requirements of this database. Second step was locating the information, which was challenging. With this information, a system design was selected to support most of features.

The main objective was to develop a database system that provides expected consumption based on PM schedules for each tool area on a weekly basis. The system had to be accessible by more than one user

The Spares Theoretical Bottoms up Estimation system was designed with an MS Excel user interface. This system allowed for ease of development, scalability and user flexibility. Most of the current databases allowed the user to interact with MS Excel, and therefore required no additional learning. Furthermore, MS Excel allowed faster scalability with the use of MS SQL in the back ground, which is a relational database query similar to MS Access. Although MS Access delivered the ease of summary reports, MS Excel had pivot tables and charts that would provide some of the same information, but with flexibility to change the reports. Fig. 4.2.-1 provides comparison between SQL and Access 2000 features for ease of development and flexibility.

Fig. 4.2.-1 Microsoft TPC WhitePaper.

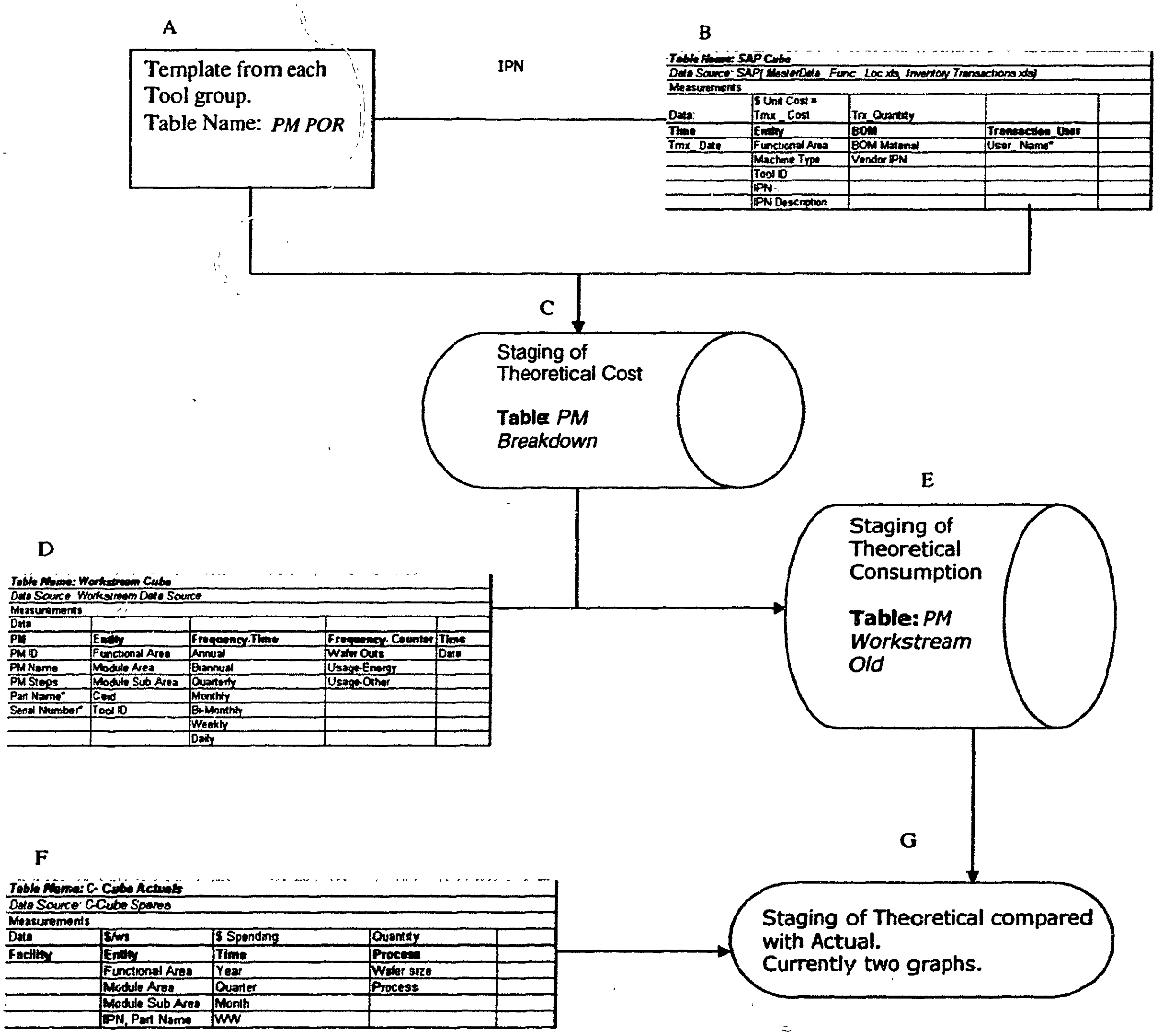
The following table outlines major operational and design differences between SQL Server 2000 and Access 2002.

Feature	Microsoft SQL Server 2000	Microsoft Access 2002 (JET)
Database size	Terabytes	2 gigabytes (GB)
Objects in database	2,147,483,647	32,768
Number of concurrent users	**Unlimited**	255
Failure recovery	Point in time recovery; failover cluster support	Recoverable to the last backup
Security	Integrated with Windows 2000 and Windows NT security	Based on use of workgroup information file
Analysis Services (data warehousing, data mining and OLAP)	**Built-in**	None
Support for SMP systems	Built-in	None

Overall, the Microsoft SQL had the essential requirements for ease of scalability and development. The MS Excel as the front-end interfaced with the SQL system in addition to VBA programming, which allowed for a scalable and home made system.

Next step was to locate the databases that stored this information. The following diagram represents the relational database with the key features that were necessary for functional BUE. Fig. 4.2.-2 illustrates the relational diagram designed to create the automated system based on already existing data and new data setups.

Fig. 4.2.-2: Spares System Flow Diagram



Database-A has information related to parts description and part serial number, which related to a specific PM. Database-A, known as PM template indicates the quantity of parts used and frequency of the PM. PM template, Database-A, is the only missing data that had to be created manually by using information from engineering and procedures. When the PM frequency changes or parts change for a PM, Database-A would have to be updated.

Database-A, the PM template, relates to Database-B by the part serial number. Database-B contains inventory transaction information for spare parts. This system is updated automatically for any new changes, such as price reduction. The database relation between A and B create the staging database that contains the planned cost of each PM.

Fig. 4.2-3 Database B with inventory transactions.

Table Name: SAP Cube				
Data Source: SAP(MasterData_ Func_ Loc.xls, Inventory Transactions.xls)				
Measurements:				
Data:	$ Unit Cost = Trnx._ Cost	Trx_Quantity		
Time	**Entity**	**BOM**	**Transaction_User**	
Trnx_ Date	Functional Area	BOM Material	User_ Name*	
	Machine Type	Vendor IPN		
	Tool ID			
	IPN			
	IPN Description			

Database-D contains on-line information about PM scheduling. Fig. 4.2.-3 illustrates the information contained in Database D. Since this system changed every hour based on up-to-date information on the plant floor, a historical database had to be established to capture past data. A VBA program was created to capture historical data on a periodic basis. In addition, the timing was converted to Intel's calendar nomenclature of workweeks. Database-D, known as work stream cube database, relates to Database-C, staging of PM cost, by a PM Identifier. The information between the two databases creates the staging for the theoretical consumption of spare parts, Database -E.

Fig. 4.2 -4 : Database D Workstream Cube

Table Name: Workstream Cube				
Data Source: Workstream Data Source				
Measurements:				
Data:				
PM	**Entity**	**Frequency-Time**	**Frequency- Counter**	**Time**
PM ID	Functional Area	Annual	Wafer Outs	Date
PM Name	Module Area	Biannual	Usage-Energy	
PM Steps	Module Sub Area	Quarterly	Usage-Other	
Part Name*	Ceid	Monthly		
Serial Number*	Tool ID	Bi-Monthly		
		Weekly		
		Daily		

Finally, Database-E can be extracted for information on expected consumption based on planned PMs. Database-F, Spare Parts Cube, provides information on actual consumption based on inventory pulls. This is the current data that the engineers use to identify their spending consumption. Both databases can be extracted by multiple filters to compare actual consumption vs. theoretical or expected consumption. Database-G, allows the flexibility to choose multiple filters for comparison. For example, a user may want to compare theoretical vs. actual by time function, part function or PMs, etc...

At the time of writing this thesis, the system was going through validation for robustness and data integrity. The robustness and further development of this type of system should be the next step for further integration of cost conscious behavior into Intel manufacturing culture, specifically Fabrication Plant-7 manufacturing culture. This builds upon and extends the checkbook concept of spending what is expected and allotted, rather than spending unnecessarily.

5 Conclusions

5.1 Summary

In retrospect, the cost reduction program was successful in getting the process-engineering group to manage commodity costs. Since "Copy Exactly" was ingrained into Intel's culture, the thought was that the fabrication plants would perform the same in commodity cost. However, the performance was not the same, although the fabrication plants had identical roadmaps consisting of the same projects with similar timelines. The cost performance of the Fabrication Plant-7 prior to the initiation of the commodity cost program was worst- in- class for most of the engineering tool areas. After the second quarter into the program, the Fabrication Plant-7 performed best-in- class in most of engineering tool areas and saved $ seven million dollars in commodity consumption. Through the concepts of "reengineering", the commodity cost reduction program at Fabrication Plant-7 eliminated waste from its manufacturing line.

Without a doubt, the program helped cultivate a cost conscious behavior. Nevertheless, was it sustainable? Is it aligned and ingrained into Fabrication Plant-7 culture and virtual factory associated with Fabrication Plant-7? The following section will discuss the next steps to cost reduction and how to encourage cost consciousness behavior in Fabrication Plant-7 and further into the virtual factory.

5.2 Next Steps for the Organization

The next steps are sustainability of this process as it spreads into the virtual factory. One essential indicator of transfer will be the adoption of Fabrication Plant-7's process systems by the virtual factory. At the time of the thesis write-up, the engineering cost champions and budget segment leaders were transferring process systems for managing cost into the virtual factory. Whether the virtual factory will use these systems to manage cost is an important question to answer over time.

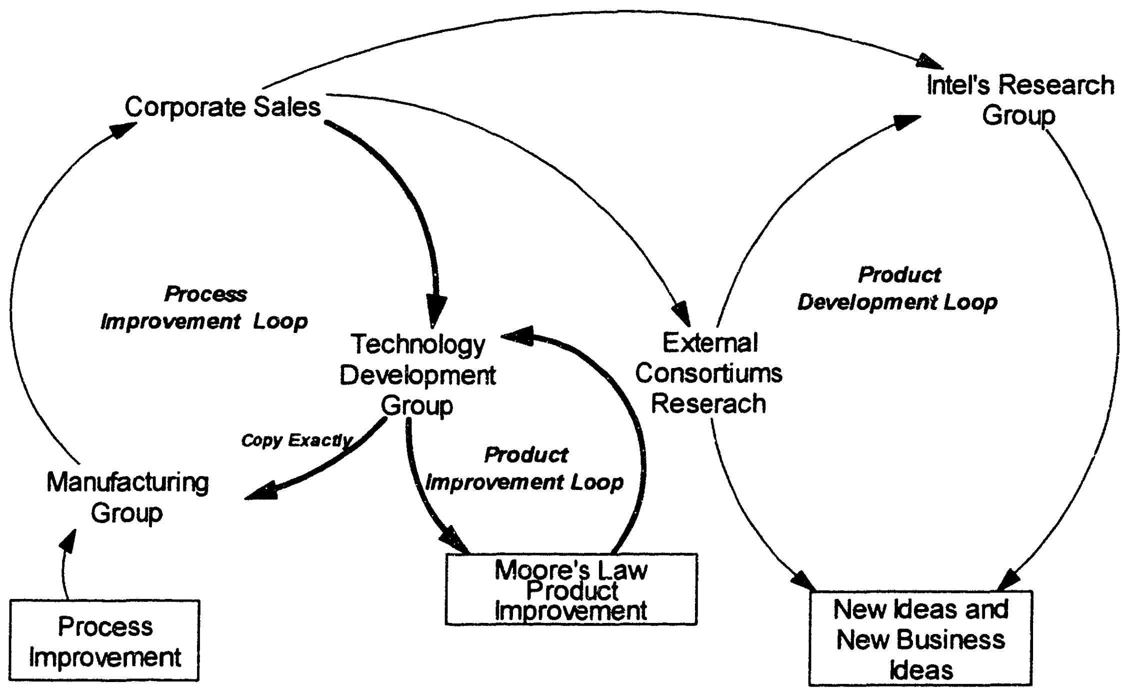
In addition, manufacturing technicians will be introduced into the cost awareness program. Since manufacturing technicians order the commodities to perform any PM or inspection on the plant floor, the awareness of cost management will make a tremendous impact. Currently, Fabrication Plant-7 is the only fabrication plant pursuing this additional effort. It is not part of the virtual factory endeavors, yet.

Besides integrating manufacturing technicians into cost conscious behavior, aligning Intel's manufacturing objectives are critical. Fabrication Plant-7 adapted its objectives to include cost-effective output. The other fabrication plants should include cost-effective output as one of their objectives to encourage the focus of cost effective solutions. As part of "Copy Exactly" operating principle, this objective should be proliferated as a shared learning across the fabrication plants.

5.3 Driving Cost Initiatives Further Upstream

Most of the cost reduction projects that were on the roadmap were projects that were successfully implemented in past products. After the projects were successfully implemented on the manufacturing product line, the information was not passed to development teams as shared learnings. Fig. 2.4.4-1 illustrates the flow of information for product development and process/product improvement loops at Intel. The information was based on numerous interviews from within Intel's value chain.

Fig. 5.3-1 Technology Strategy – Systems Dynamic Flow of Information
Intel product development, process, and product improvement cycle is based on numerous interviews within Intel value chain. This represents a system dynamic figure of how information and shared learnings flow into the different groups of the organization. In this figure, the bolded arrows represent active areas for new product introduction and process improvement. Technology Development group has been active in pushing Moore's Law to develop new products and improve the process. The manufacturing group improves the process for higher yields.



The most active loop, product improvement loop, focuses on Moore's law. It is unidirectional, but the information and the product design transfers exactly to the manufacturing group. The process improvement loop is also unidirectional. The knowledge of process improvement from manufacturing does not feed back into the

Technology Development Group. It remains in the manufacturing arena. As a result, a new generation microprocessor from the product improvement loop begins with product parameters based on Technology Development knowledge, instead of the collective knowledge of Intel's technology base groups. From several interviews with the process engineering group and technology development group, engineering continuously complains about known cost reduction projects based on past historical data of similar processes that were never exploited for the new generation product due to lack of shared knowledge. Therefore, many of these low risk cost reduction projects were tested and implemented in manufacturing during process stability, when these projects could have been tested and implemented before transferring to manufacturing.

The product development loop includes the emergence of entirely new businesses and products besides the microprocessors. The loop introduces new product lines in the telecommunication, wireless systems, etc markets, but the new products are currently only twenty percent of Intel's revenue. Therefore, they have not become the cash cow, like the microprocessor. The perception is that the focus on Moore's law, disciplined operating principles likes "Copy Exactly" and fast clock speed product, reduce the interaction between research, technology development and manufacturing group.

If the manufacturing group transferred the essential process and product learnings to the product development group, the next generation product would have tighter specifications and parameters based on manufacturing experience. The manufacturing product life cycle would include cost savings further upstream, rather than later. However, the fast clock speed may not provide the Technology Development group with enough time to implement the learnings.

5.2. Recommendations

5.2.1. Integrating Cost Additions

Cost consciousness can further be ingrained into the culture by continually providing systems that will encourage a disciplined approach to reducing cost. The concept of balancing the checkbook provides a framework for developing new systems to ensure a clear message about cost reductions. One flaw to the current systems is that it did not include cost additions or debits, within the balancing the checkbook framework. For example, the projects/experiments listed in the virtual factory project tracking database were only associated with cost reductions. However, another database had projects/experiments that were associated with yield or output improvement projects that were not for cost savings. These projects increased cost. Within a specific tool area, both cost reduction projects and yield improvement projects were implemented in parallel at different plants. Therefore, the projects cancelled each other in terms of cost, and the actual cost reduction savings from cost reduction project was not visible.

In order to integrate the concept of "balancing the checkbook", credits and debits should be taken into account. Because the information is skewed, it does not provide a true projection that cost savings will be realized, if cost debits are not accounted for in the total plan. Combining the two databases would help provide the total picture of commodity cost progression and management in manufacturing. It would be a low cost initiative for implementation, since the database systems are already in place. It will take some collaboration efforts, buy-ins and communication to implement.

5.3. Final Thoughts

With economic unpredictability, thinking lean is a crucial manufacturing endeavor for short and long term sustainability. However, a culture that places a strong emphasis on discipline around manufacturing operations through "Copy Exactly" can stifle innovation. The "Copy Exactly" manufacturing principle will become more of a core rigidity, rather than core competency or competitive edge.

Through the concepts of reengineering, the cost reduction process and strategy were developed and implemented for cost reductions at the ramp stage of production. A simple framework of "balancing a checkbook" provides the foundation for a cost conscious culture. It was purposeful and very successful for the Fabrication Plant-7. However, changing culture is not easy, but many corporate leaders have led one to believe that change is more readily possible in terms of chaos or crisis. For example, Andrew Grove believes that only the "paranoid survives". The feelings of insecurity and chaos can enable change into an organization, but may not be the best feeling or environment to work in. It must be counterbalanced with an incentive worth staying.

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