# AN ANALYSIS OF THE EFFECT OF TECHNOLOGY TRANSFER METHODOLOGY ON MANUFACTURABILITY AND SUSTAINABILITY

by

Eric Sebastian Fears

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and

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Signature of Author ____________________
Department of Electrical Engineering and Computer Science
MIT Sloan School of Management
May 6, 1994

Certified by ____________________
Lionel C. Kimerling, Professor of Material Science and Engineering
Department of Material Science and Engineering
Thesis Supervisor

Certified by ____________________
Charles H. Fine, Associate Professor of Management Science
Sloan School of Management
Thesis Supervisor

Accepted by ____________________
Frederic R. Morgenthaler, Chairman, EECS Committee on Graduate Students

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Intel wishes to establish multiple factories to run a single process. Similar products produced by the different factories must perform "identically". To achieve this goal Intel currently uses a technology transfer program in which the manufacturing facility copies the development facility in all physical and process procedural respects unless there are overwhelming physical, regulatory, or economic justifications to not do so. The reasoning is: If the physical and process procedural aspects of the development facility are replicated identically then the process output at the manufacturing facility should be identical to that of the development facility. Intel has named this concept the Copy EXACTLY! program.

In this thesis I have presented a framework for the development and evaluation of technology transfer programs and examined the Copy EXACTLY! technology transfer program within that context. I concluded that the Copy EXACTLY! program compares favorably with the theoretically ideal program but that Intel may benefit from a more comprehensive design transfer package. I identified a trend in successive learning curves as Intel's manufacturing operations move from a less structured technology transfer program into the Copy EXACTLY! technology transfer regime. This trend indicates that there is learning going on at Intel's manufacturing facilities, however, it does not prove that the learning can be attributed to the Copy EXACTLY! program. I have also examined some of the motivational/incentive policies at Intel and found that Intel may be able to increase the alignment of it's employees.

Thesis Advisors

Lionel C. Kimerling, Professor of Material Science and Engineering

Charles H. Fine, Associate Professor of Management Science

This work is dedicated to my family:

Joseph Fears, Sr., my father.
I can only hope that he knew my love for him and that I recognized the great sacrifices that he and my mother made to ensure that my siblings and I had "opportunities".

Maudie Mae Fears, my mother.
May she know everyday that I love and admire her. Through her life she has taught me the meaning of the words honor, justice, love, sacrifice and duty. Without her love and encouragement I would not have come this far.

Joseph Fears, Jr., my older brother.
A man who I have admired and patterned much of my life after. It is he who taught me the joy and understanding of the Fine Arts.

Cheryl Veronica Fears, my older and only sister.
I have learned from her what hard work truly is and through her eyes I see a world in which people care for others.

Shawn Davis Fears, my younger brother and confidant.
His advice and achievement over the years has inspired me to dream dreams and pursue goals I would never have thought of on my own.

Much of the new management culture and philosophy centers around the concept of teams and their role in achievement within organizations. Under this new "paradigm" individual accomplishment is not to be recognized without an accompanying recognition of group or team accomplishment or at least contribution to the success of the individual. This recent popularity notwithstanding I express my sincere recognition of the following people who have given me access to the resources that I needed to do the research and investigation necessary to write this tome.

I offer my deepest appreciation to David Marsing whose vision and sponsorship made this project a reality.

I thank both of my corporate supervisors: Anne Polino who was not only my corporate management supervisor but also a mentor and cheerleader and Jim Ellington who was my corporate engineering supervisor and mentor. The data that I used in determining the learning rates would still be incomplete without the help of Lambert Calvert et al.

I am also grateful to Noel Allen, Shaun Bratcher, Susan Capener, Kim Dickel and Sandra Schulthess all of whom made my stay at Intel much easier by guiding me through the "Intel way" of administrative red tape.

I thank the engineers, manufacturing technicians, managers and others at Intel Ireland Limited (Fab 10), Intel California Technology Manufacturing (D2), and Intel Albuquerque (Fab 9 Expansion) whose assistance during my research was valuable and much appreciated.

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Even though the practice of moving ideas, manufacturing processes and other forms of technology from the Research and Development lab into a manufacturing facility has existed almost as long as the concept of a separate Research and Development organization, the term "technology transfer" is relatively new. However, given the exponentially increasing rate of technological advancement and the increasingly global and diverse competition in the marketplace, the traditional ad hoc approach to technology transfer must be supplemented by a methodology that is systematic, reproducible and based upon sound scientific and engineering principles. An appropriate paradigm for technology transfer can eliminate wasteful duplication of effort between the development organization and the manufacturing organization, encourage design for manufacturability by providing an avenue for the necessary feedback of information from the manufacturing organization to the development organization; influence the development of more robust manufacturing processes by providing "real world" experience and information to the research and development labs; reduce the number production start-up problems thus reducing both the cost of a production line start-up and the time to bring a product to market. An added benefit of a structured, scientifically based technology transfer program is that variations in products and/or processes can be reduced as it is possible to have multiple facilities running essentially identical processes. If used properly, this benefit can promote shared learning across organization boundaries.

This thesis presents a study of the Copy EXACTLY! technology transfer program at Intel Corporation. I will focus on the organizational challenges of technology transfer and present a framework for analyzing the implementation of a technology transfer program.

Technology transfer programs have the potential to radically alter the working interface between the Research and Development organization and the Manufacturing organization; they can also have tremendous impact on a company's bottom line. Thus it is important that executives, managers, engineers, scientists and technicians all be involved in the design and implementation of the technology transfer program if it is to be a corporate asset rather than a liability.

# CHAPTER 1: A Framework for Technology Transfer

## 1.1 What is Technology Transfer?

This thesis is generally about organizational learning and learning organization, broadly about technology transfer programs and manufacturing firms, and specifically about the Copy EXACTLY! process/product technology transfer program at the Intel Corporation. If one wishes to evaluate something like a technology transfer program then one must have a reference standard in mind while conducting that evaluation. But how does one go about establishing that standard? It has been said that :

> "You get what you measure."

In this case it is more important to ask — "What are you looking for?" For it is the answer to this question that will allow an organization to establish the short range and long range goals that are appropriate to achieving the wished for results within the framework of the broader organizational goals. Thus it is important that this work begin with an examination of the various meanings attached to the concept of technology transfer.

Each of the fields of human inquiry has to one extent or another a conception of how technology transfer should be defined — that is each discipline has its own version as to what constitutes technology transfer. It may be that one of these fields posses the correct vision of technology transfer. It is more likely, however, that the concept of technology transfer that needs to be embraced by a true learning organization is a composite of these discipline specific visions.

In Economics the definition of technology transfer has focused more on the term "transfer" and has been analyzed by Vaitsos, who laments its inappropriateness for transfer connotes the free, non commercial movement of something from one location or possessor to another. In fact, however, with technology, what is usually involved is a "sale" of such technology. For this reason, the term "commercialization of technology" has been argued to be generally more appropriate.

Brooks' generalized concept of technology transfer is useful to understand the economist's perspective:

> "Technology transfer is the process by which science and technology are diffused throughout human activity. Wherever systematic rational knowledge developed by one group or institution is embodied in a way of doing things by other institutions or groups, we have technology transfer. This can be either transfer from more basic scientific knowledge into technology or adaptation of an existing technology to a new use. Technology transfer differs from ordinary scientific information transfer in the fact that to be really transferred, it must be embodied in an actual operation of some kind."

From an anthropologist's point of view, technology transfer takes its place in the context of cultural evolution. Anthropologists argue that a technology is adopted when people or groups find it desirable and possible to change what they are doing in ways that involve particular uses of that technology. Such people and groups are the active, initiating elements of the change in technical practices. Anthropologists are more interested in studying the agents and objects of changes and its "spin-off" effects.

The sociologic literature lacks the phrase "transfer of technology." Thus the issues involved in technology transfer have been treated by sociologists through the study of diffusion of innovation. Where the term "diffusion" is used to include both the planned and the spontaneous spread of innovation. Sociologists argue that the probabilities of a new alternative being superior to previous practice are not exactly known by the individual problem solvers. Thus, they are motivated to seek further information about the innovation in order to cope with the uncertainty that it creates. So the diffusion of innovation is defined as a social process by which an innovation is communicated through certain channels over time among the members of social system.

In business and engineering activities, technology transfer is viewed in more specific terms and is usually conceived as the transfer of specialized know-how, which may be either patented or non patented from one enterprise to another. As Baranson defines it, transmission of such knowledge enables the recipient enterprise to manufacture a particular product or to provide a specific service. Other researchers define technology transfer as the transfer of know-how. As distinct from the sale of machinery and equipment which embodies technology, they argue that the transfer of technology, in most cases, calls for a sustained relationship between two enterprises over a period of time, so that the receiving enterprise can reproduce the product with a desired level of quality standards and cost efficiency. This relationship model of technology transfer is consistent with the work of Contractor and Robinson. Chesnais argues that the transfer of technology implies the transfer to the recipient not only of the technical knowledge needed to produce the product but also of the capacity to master, develop and later produce autonomously the technology underlying such products.

In order to better understand the broad nature of technology transfer, we need to first solve its definition problems and to resolve confusion about technology transfer.

## 1.2 How does Technology Transfer Fit Into a World Class Manufacturing Organization?

Technology transfer involves more than just technological or engineering dimensions. With improved understanding of the multidimensional facets and the multidisciplinary views of technology transfer, engineering and technology managers and/or policy makers can better formulate strategy so as to transfer technology more effectively. Though technology transfer, as a subject of study, has accumulated a vast body of research, our knowledge about technology transfer is still fragmented, unsystematic, and single perspective oriented. Consolidation, synthesis, and systematic analysis of the technology transfer literature is of great importance for those individuals and organizations that wish to be leaders in the coming decades.

Research without implementation is akin to good strategy without execution. In both cases, the investment in developing new approaches to a problem is lost through a failure to move the solutions from those who generate them to those who can use them. In the past, transferring ideas and technology from the lab to engineering practice was carried out largely on an ad hoc basis. However, with the accelerating pace of technological development and the pressing issue of increasing competition on a global scale, this type of approach will no longer suffice. The ability to rapidly move new products and processes from development to practice, or to the marketplace, is generally recognized as a key to improving a nation's competitive position in the world. Management teams and engineers have been slow to adapt to this need and must begin to recognize that the practice of technology transfer is itself an integral part of their activities that directly influences the effectiveness of many of their efforts. Technology-transfer activities must now be systematically planned and scientifically based in order to be successful.

On the surface, transferring technologies from researchers to practitioners would seem to be a relatively straightforward task. However, the increasing complexity of new technologies and the sheer size, scope, and multijurisdictional, multinational character of many agencies or corporations requires a new approach. Engineers must now recognize the need to plan their "delivery" mechanisms in order to deal with this complexity. They must recognize who is to be served -- and this may include people of varying technical training and backgrounds. The magnitude of change presented by a new technology also will influence the program used for its introduction, as will the increasing trend toward multidisciplinary solutions to today's problems.

The process of developing technology transfer programs and strategies can and must proceed in parallel with the development programs they are destined to support. The products will affect not only engineering design practitioners, but also contractors, material suppliers, and of course, the broad-user community.

This hierarchy of systems generates a hierarchy of technology transfer needs. This means that implementing the findings of the development program will involve many steps, diverse types of programs, and substantial cost. Programs to accomplish this purpose must be tightly focused and must direct their actions so that the right information is provided to the right people at the right time. These same principles apply to implementing the products of both large and small development programs.

Sections 1.3 and 1.4 explore the design of technology transfer programs. Although developed in the context of semiconductor microprocessor manufacturing technology, it applies to other areas as well. It begins with a discussion of the mythology that has grown up around technology-transfer programs and that now often impedes the successful implementation of new technologies. From this, a general framework for technology transfer program planning is developed and a set of specific guidelines for the design of such activities is also presented. The thesis also includes a brief discussion of some new enabling technologies that will facilitate the implementation of these programs in the future.

Technology transfer allows the manufacturing engineer to focus on process improvement: Copy EXACTLY! specifies that the destination manufacturing site should duplicate as closely as possible the process {including equipment, materials, etc.} that is running at the originating site. Theoretically this allows the destination site to reach targeted production volumes, quality levels, and reliability levels with fewer problems than traditional methodologies. Thus the ramp time is shorter due to fewer problem solving iterations and plant/line shut downs, freeing up time for the technician and engineers and managers. This time can be used by either group to investigate and evaluate process improvement opportunities, additional market opportunities, etc.

Under Copy EXACTLY!, the manufacturing process must be analyzed and understood at a depth the average development or manufacturing group has never dared do.

## 1.3 What are the Obstacles to Effective Technology Transfer?

Technology transfer is a recognized and vital part of bringing any product to market. Why is it that so few companies do it well? Having now experienced technology transfer programs from the perspectives of research engineer, development engineer, and management, I believe that the barriers to designing and implementing an effective technology transfer program can be summarized by the following myths.

Myth One: Any Transfer Technology is Better than None

This myth is most frequently invoked by those concerned by the time and costs involved in providing an adequate program of activities for implementing a new technology. At the best, however, such an approach results in programs that work only by accident. In most cases, the marginal technology transfer program can result in marginal use of the new technology. In many cases, a new technology, poorly introduced and justified dies on the operating table of technology transfer. In other cases the company loses due to loss of productivity

1. of the engineers and technicians who try to implement a poorly understood or poorly designed process, and
2. of managers who try to avoid blame, fix blame and assuage customers, shareholders, and "Wall Street".

Myth Two: The Post research Myth

Under this philosophy, technology transfer programs are only undertaken after a research program is over. Knowledgeable researchers , however, know that, like any product, practical research must be targeted to the requirements of the users for which it is destined. There is no better way to kill a new technology than to present it as a fait accompli to its potential users without having ever consulted or involved them in the development process. Having a technology transfer program that allows the users to provide input into the research-and-design process helps them to "buy in" to the process and inevitably results in a smoother, more cost-effective, and timely implementation process.

Myth Three: The Segregation Myth

This myth postulates that technology transfer programs are separate from the continuing process of technology development. Following this philosophy cuts the feedback loop between the users of technology and the developers of technology, thus slowing both the research and development process and subsequent technology transfer activities not to mention the downstream manufacturing processes.. For an agency or institution to make the best use of its research and implementation resources, permanent structures must be in place to allow feedback and interaction between researchers and technology users.

Myth Four: The Indispensable-Researcher Myth

Researchers are not good at everything. Many are not good at all at communications or at the types of activities that are required to allow potential users of a technology to develop the understanding required to use it on a daily basis. In spite of this fact, many agencies still use their researchers to head the technical aspects of Technology transfer programs. There is little doubt that when researchers communicate well they can be a real asset to a technology-transfer program. However, where they do not, they can delay and even temporarily halt a new technology. Good Technology transfer programs employ the best communications, training, and teaching strategies available. They exploit researchers in a support role, highlighting their contributions but using them sparingly and at key points in the program where others have neither the technical authority nor the capability to carry such a role.

Corollary to Myth Four: The Indispensable-Manager Myth

Likewise managers are not good at everything. Many are not good at all at assessing the underlying benefits of a technology or at distinguishing the difference between alternative technological choices. These persons can also be an asset to a technology transfer program when they understand their limitations and the implications of the decisions that they make. These managers, with neither the technical authority nor the capability to carry out such a role should always seek out a knowledgeable engineer or technician before making a decision on a specific technology transfer program.

Myth Five: Bigger is Better

The effectiveness of a technology-transfer program is not proportional to its cost. While there is a relationship between the quality of a program and its cost, the most effective activities are concentrated on targeting program elements to the specific audiences that must be addressed, with the most appropriate tools at hand. This is not always the most expensive or most spectacular way to do things. But it is the most effective. Focus is everything.

Myth Six: The Single-Element Program Myth

This corollary to myth one generally sees technology transfer as an activity that can be carried out using a single tool. Reports, executive summaries, and workshops or seminars are the most popular tools chosen for the purpose. These vehicles are chosen because they are familiar, easy to organize, and generally require little or no specialized expertise to put together. Most commonly, invocation of this myth in practice results in a program that misses its intended target altogether. The market for technologies is always segmented, and each segment has specific needs. Effective Technology transfer activities gear their program design to this fact.

Myth Seven: The Passive Delivery Myth

Also known as the classroom technique, the passive delivery philosophy of technology transfer places potential users in a passive learning situation, where the main vehicle for transferring the information is by lectures. This technique is inefficient as a technology-transfer mechanism, but excellent for curing insomnia in potential technology users. The old saying learn by doing has a sound basis in fact. Educators ana trainers long ago learned the value of involving the student in the educational process in an active way. Experiments, computer simulation, active field demonstrations, and many other means exist to move information effectively to target audiences. The written word, while always necessary as a reference document, should not be relied upon as the primary vehicle for technology transfer.

## 1.4 Tools for Technology Transfer

Overcoming the current mythology of Technology transfer programs requires looking at the problem of implementing new technologies from a different standpoint. The development and implementation of nuclear energy provides a good example of the complexity involved in moving a technology into active use in a society. It is not only the engineers who will run the generating station that must be educated but informed policy choices must be made by those responsible for the implementation decision. In addition, electricity users concerned with costs, reliability of service, and more broadly based societal interests who may be affected by environmental or safety issues must also be made aware of the impacts of the generating technology. Finally, all of these factors must be addressed prior to implementation of the technology. In other words, the technology-transfer program related to such an issue must take place at different times and address information needs that vary by the interests and requirements of the target group. A simple one-shot program will not do the job.

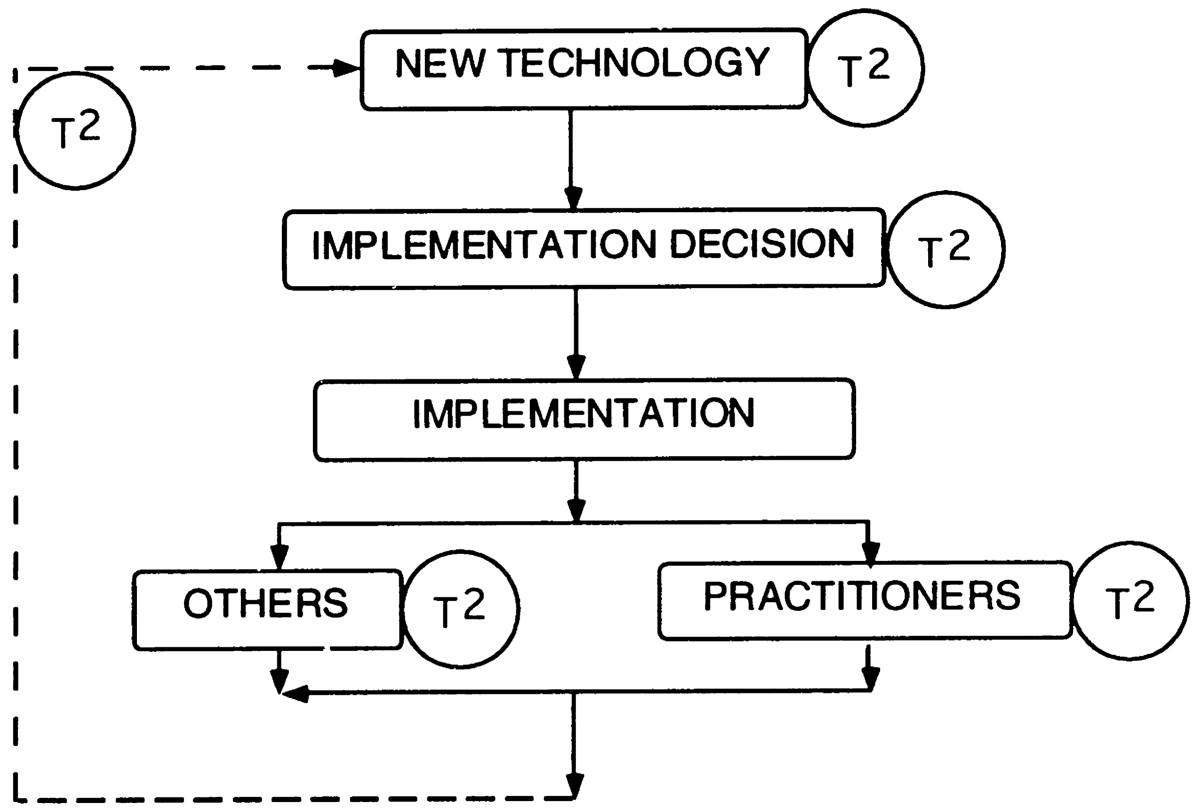


Figure 1.4.1: Technology Transfer : When to Do it

Figure 1.4.1 illustrates this problem. It shows the stages typical to the implementation of a technology and the times at which some form of technology transfer action is required. Strategic planning of technology transfer programs must begin when specific research is undertaken, or at least while the program is still under way. Once research is complete and a technology is available, those responsible for deciding whether to incorporate the technology into current practice must receive the information they require. Often, this information will take various forms and address both technical and policy issues Once implementation has been decided upon, practitioners who will use the technology and other groups affected by it must be informed and educated in order to ensure successful adoption of the product of the research. These principles apply whether the research program is large or small. Failure in implementing research findings can most often be related to the absence of adequate Technology transfer measures at one of these stages.

**Technology Transfer Planning Framework**

Fig. 1.4.2 incorporates the aforementioned principles into a conceptual planning framework for technology transfer programs. In this framework, the stepwise nature and variable information needs of technology transfer activities are borne in mind, and the planning of the program moves from a strategic level through to the specific selection and design of its tactical components by considering four primary factors: (1) Planning factors; (2) sector impacts; (3) technology level; and (4) discipline considerations. Considering these four factors helps identify the specific stages at which various elements of the program are required. It also assists in the design of these elements to serve the specific information needs of the target groups, both in terms of technical content and appropriate delivery vehicle. The four factors are described briefly in the following paragraphs.

Planning Factors

Planning of the program focuses on strategic considerations. It is at this level that the overall shape of the program is set out. Candidate times at which various technology transfer activities are required are enumerated. Potential impacts of the new technology, and target groups with interests in these effects, are identified. These strategic considerations are used as input to the other three stages of development of the technology-transfer program. In a sense, this stage is analogous to a technology market study.

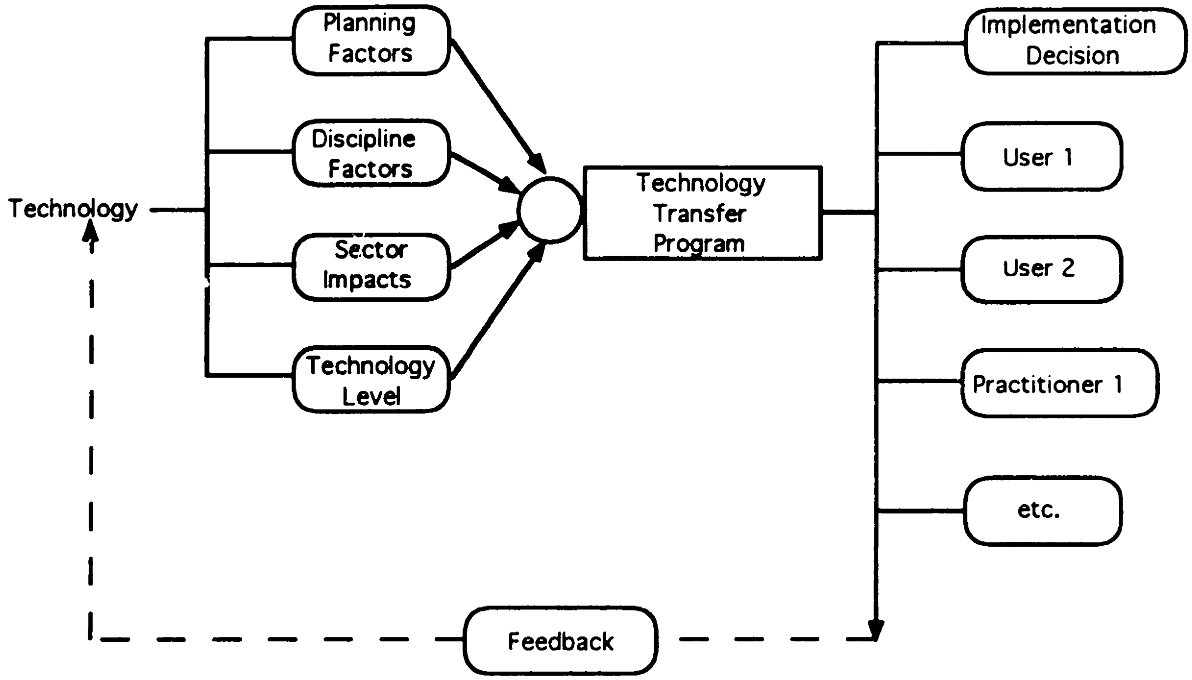


Figure 1.4.2: Technology Transfer Framework

Sector Impacts

Implementing new technologies has impacts far broader than just at the practitioner level. In the semiconductor process/product technology domain, for instance, OEM and internal customers are obvious target groups. However, within those groups are senior managers, lead engineers, middle-level management, designers, and technical support staff. Each of these groups has different information requirements that must be considered. For each, the delivery mechanism may be quite different. Nonetheless, all of these groups will be involved in the implementation process.

Linked to the policies of the owning or operating agency, however, are other target groups with interests in the implementation of new semiconductor process/product technology. Consultants, contractors, material suppliers, and marketing are good examples. In addition, user groups, including scientific and engineering computer users, business computer users, and others, also have a vested interest in the impacts of new semiconductor process/product technology — but their interests and information needs are substantially different. Each must be considered in the design of the technology transfer program

Technology Level

Moving people away from the comfort zone generated by known processes and technologies necessarily involves overcoming fears and vested interests of all sorts. Sound arguments must be put forth to justify changing technologies; those arguments must be cogent, clear, and appropriate to the interests of the target group. In a sense, the technology transfer program is the "grease" that allows the push for innovation to overcome the inertia of rest.

The amount and type of grease will depend to a great degree on the quantum of change the new technology introduces. Generally speaking, the greater the change, the greater the level of effort required to introduce the change successfully and the broader the range of target groups to be considered. In the context of this framework, technologies are classed into three general categories: evolutionary, innovative, and revolutionary. Each of these categories represents an additional step in the departure of the new semiconductor process/product technology from the status quo.

Evolutionary changes generally build on existing technologies, use familiar terms and familiar applications, and can be introduced within existing policy and specification boundaries. The range of target groups usually is restricted and the type of program can be specifically directed to their technical needs. Process improvement activities are the most common class of this kind of technological change within the scope of semiconductor process/product technology. Innovative changes often introduce new equipment or processes and may carry with them specification changes or policy implications that must be addressed by higher administrative levels within an agency,. They also usually imply some significant impacts on outside interests, including contractors, suppliers, OEMs, etc. The range of target groups thus broadens considerably, as do the types of candidate technology transfer measures that might be combined in such programs. New process/product generations are the most common class of this kind of technological change within the scope of semiconductor process/product technology. Revolutionary technologies do not often occur. When they do, they represent major departures from current practice and often carry with them substantive benefits. Consequent technology transfer programs are usually highly complex and costly.

Discipline Factors

Engineering and management are becoming increasingly complex and more and more often invoke the use of professions and disciplines that have not traditionally been associated with semiconductor technologies. While economics and chemistry (materials etc.) are two obvious examples that have been present for some time, other domains such as environmental sciences, system dynamics, and cognitive sciences (artificial intelligence and expert systems) are now also playing significant roles in various aspects of semiconductor engineering. Introducing new technologies that draw on these domains and that may be unfamiliar to many practicing production personnel has significant implications for the design of any associated technology transfer programs.

## Using the Framework

Technology transfer programs must begin at the early stages of a development effort. All of the four key factors must be examined in order to determine what activities must be done, when they should be done, and how they should be carried out. In addition, the feedback loop incorporated into the process provides the impetus for new research and also gives users the opportunity to help define what such research should be. This last process inevitably paves the way for even smoother technology transfers in the future.

# CHAPTER 2: Intel's Copy EXACTLY! Program

## 2.1 Description of Copy EXACTLY!

Once a process technology is developed and proven at the Technology Development (TD) center it is proliferated to the chosen manufacturing sites. Due to the increasing cost and complexity of state of the art process technology, Intel believes that the quickest, most efficient, predictable and reliable method available to bring a new Fab on line is to copy the originating Fab in most every detail. This paradigm of technology transfer to establish a process (manufacturing) technology at a facility is called the Copy EXACTLY! program. The principle ideals of Copy EXACTLY! are very simple and straightforward:

1. Copy everything exactly from the originating site unless physically impossible to do so, impractical or there are overwhelming economic or competitive reasons not to copy.
2. Every exception {item not copied exactly} requires a review and approval process {white paper and PCCB}
3. All member Fabs must work together to improve the process and systems before and after the transfer.

These three simple principals, however, are much harder to implement, in the real world, than they are to state on paper. In practice the Copy EXACTLY! program does have a broad but limited scope — the areas that are covered by the program are :

- PR generation through process qualification for equipment
- Equipment configuration and hookup
- Facilities systems at point of use
- Process related materials {i.e. ion beam targets, raw silicon waters, etc.}
- Metrology
- Cleanroom performance
- Process recipes
- PM and Operating procedures
- Process monitors

Areas that will not, at least initially, be covered by Copy EXACTLY! include:

- CIM issues
- Manufacturing systems {AMHS, etc.}
- Organizational structures
- Data analysis tools
- Strategic differences {i.e. Fab size, Fab location, etc.}

Copy EXACTLY! also establishes process wide {as opposed to Fab specific} procedures for the approval and/or escalation of technical and tactical issues

This set of actions and priorities were established as a means of achieving the goals of the technology transfer program which are:

1. To reduce risks in process transfer

2. To produce equivalent yield levels at all sites for a given process
3. To promote shared learning among the member Fabs
4. To reduce the time and effort required to ramp a Fab into full production
5. To produce chips that perform identically across all Fabs running the same process technology
6. To create synergy between the member Fabs.

As an aid to achieving these goals, many functional, cross function and inter facility teams were established. It is through these teams that technical and business issues are uncovered, researched, studied, discussed and resolved or elevated to a higher team or authority. Most, if not all, of these teams have representatives from each of the Fabs that are currently running or will be running a given process technology.

The Copy EXACTLY! program addresses four hierarchical levels of dependence in copying a process technology from one site to the next (See Figure 2.1.1). Level one is the Physical Impacts to a process such as Equipment Installation and Hookup, Recipe parameters, Clean room procedures, etc. These items are about as basic as one can get at the macroscopic level. It is believed that unless the basic material inputs, construction, layout and operating procedures are the same as the originating Fab, there is small chance, if any, of matching any of the remaining levels or achieving statistically identical outputs. Moreover, there would be no synergy or shared learning among the different Fabs should this level of matching not be achieved. The second level of matching is termed Process Step/Equipment and covers such items as etch notes, deposition notes, film composition, etc. This level of matching is needed to ensure that individual process steps are matched as closely as possible. The major advantage achieved here is that Fabs may assist one another with problem solving and continuous improvement as they are running processes that are identical except for well documented and approved differences. The third level of matching covers the physical and electrical characteristics of the final product. This level is termed the Module Level and is the point in Copy EXACTLY! where the concern for match focuses more acutely on the final product than on the process and equipment. This is the first level at which one can determine if the previous two matching levels are indeed achieving the desired results. The final level of matching concerns such issues are yield, reliability, electrical performance of the product, etc. This level, the product level, is where the payoff of the previous three levels of matching is achieved in the marketplace.

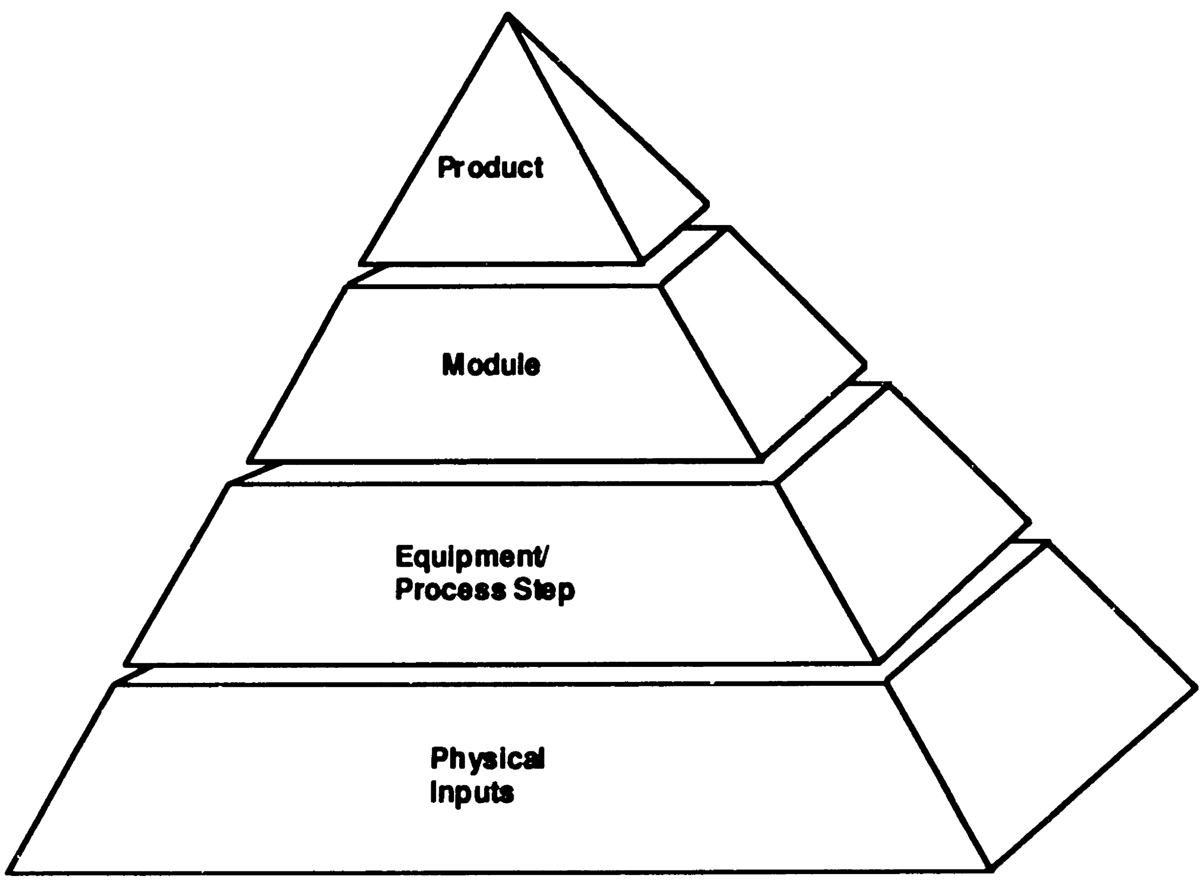


Figure 2.1.1: The Copy EXACTLY! Pyramid

As a result of the matching that occurs under Copy EXACTLY!, it should be possible to:

1. Implement fairly aggressive Fab start-up schedules
2. Implement fairly aggressive yield ramps
3. Minimize customer certification requirements by establishing a virtual factory
4. Adjust Fab-loading without the need for customer qualification or notification

## 2.2 Who Leads the Technology Transfer Program?

The vision of fully-implemented Copy EXACTLY! in a manufacturing organization is an attractive one: process technology transfers result in factory startups that are relatively fast with yields that are equivalent to those of the originating factory, cross factory learning is promoted due to the synergy created by having several "Fabs" all running "identical" processes and the output from the Fabs are statistically indistinguishable. The role of the manufacturing engineer, in this vision, is:

1. to ensure that the process is copied exactly;
2. to ensure that the process is stable and running; and
3. to continuously improve the process under the supervision of the Process change control board (PCCB).

But how does Intel assure that these corporate wide goals are being met by its various technology development and manufacturing operations around the world? How can the top managers be assured that Intel is indeed moving toward its future?

The success of Copy EXACTLY! depends on the involvement and commitment of people at all levels within the organization. From managers to engineers to technicians. The skills needed at each level are neither extraordinary nor difficult to acquire but they do require a diligence in application that has rarely been seen outside the military services. It is incumbent on every manager, engineer and technician to constantly and continually evaluate and direct his daily actions in accordance with the principles of the Copy EXACTLY! program.

In order to foster the dissemination of Copy EXACTLY!; to ensure a common vision of Copy EXACTLY! among "sister" Fabs; to facilitate organizational learning and to ensure that all "sister" Fabs are running identical processes, Intel has instituted hierarchical teams at the several levels of organization within a Fab and between Fabs as well as implementing cross-functional teams. At the operational level, these teams are used as technical forums in which issues of a technological or process procedural nature are aired and decided upon. The technical forums are useful for identifying deficiencies in process technology across sites; determining risk and making recommendations on how such issues should be resolved. The final arbiter, however, is the Process Change control Board (PCCB) which has ultimate authority on any issue that affects wafer processing.

This team based approach has many advantages. The intraorganizational learning between Fabs is greatly increased due to team members from the different Fabs engaging in discussion, fact finding and problem solving. The use of cross Fab teams also avoids duplication of effort - as each Fab does not have to function in isolation. Designed experiments can be distributed among the various "teamed" Fabs in order to improve the speed and quality of process improvement.

Finally, the PCCB {a team consisting of representatives from each of the member Fabs} can ensure that each of the member Fabs are running identical processes; are converging to the established standard process technology or have a well documented and necessary difference from the established standard process.

This team approach is a necessary but not sufficient condition for the proper and efficient deployment and utilization of Copy EXACTLY! Without local representation, it would be very difficult for a board of engineers, managers and technicians to establish controlled standards for a process technology throughout a company's manufacturing organization and to coordinate each of the individual member Fabs so that they are running identical or nearly identical processes.

## 2.3 Who Maintains the Rules for Copy EXACTLY! ?

Much of the recent literature on manufacturing management has focused attention on the paradigms of Total Quality Management and Total Preventative Maintenance (TQM and TPM respectively). Under these pair of paradigms, production workers {technicians} have responsibility for Statistical Process Control, product and/or process improvement, and equipment maintenance. The arguments for this arrangement are based on the belief that the production worker is the individual that is first to see a problem is the person most familiar with the process equipment and is the person that must constantly live with the manufacturing process and equipment. The use of TQM and TPM allows the production worker greater freedom in and control over the manufacturing process, this can in turn instill in the production worker a greater sense of pride of workmanship and responsibility for the quality of the output.

It is these same guiding principles that must be used in the management of Copy EXACTLY! However, instead of just empowering the production worker, the whole workforce must be empowered. It is the technicians who are best able to recommend the "best practices" methods for workspace layout, PM procedures and work flow. It is the Engineers {production, process, equipment, development, design}, however, who are best qualified to determine optimal process operating characteristics, equipment layout, PM schedules and process flow. While it is the managers function to determine fiscal and temporal budgeting constraints, work priorities and to set the incentive systems in place. Each of these must have had their input into the establishment and implementation of the Fab, and ultimately the Copy EXACTLY!, operating policy. Without timely, thoughtful input from each of these groups, the probability of success in running a Fab at all, least considering operations under Copy EXACTLY!, would be burdensome, slow moving, quirky and unreliable.

The need to have the three levels involved in the policy making process does not imply that each group has equal control or authority to act, but rather highlights the need for multilevel, functional and cross-functional teams. It is through the teams that issues are discovered, studied, discussed and resolved. It is these teams which provide for the integration and implementation of the various technical, managerial, operational and regulatory concerns at each level within the member factories and functions.

## 2.4 Discussion of Copy EXACTLY! Strengths and Weaknesses

While at the Intel Corporation, I conducted interviews with managers and engineers {see Appendix A}. I also administered two surveys {see Appendices B & C}. The interviews were used to narrow the scope of my research to the Copy EXACTLY! program in general and to specific problems associated with the implementation of the program.

After specific problems were identified, the first survey was used as a screening instrument to determine the major areas of strengths and weaknesses associated with the Copy EXACTLY! program. This instrument provided the basis for the second survey. The second survey was used to quantify specific issues associated with the strong/weak areas identified from the first survey, in order to determine the high leverage points in the Copy EXACTLY! technology transfer paradigm.

The largest problem with the Copy EXACTLY! program is that no one knows what essential to be copy, what is nice to copy and what is a waste of resources to copy. It is here that the program falls to Myth 5: Bigger is better. Copy EXACTLY! has evolved over the years to a program that encompasses nearly the entire Fab from building design and construction down to which direction you wipe a swab when cleaning a tool to exact placement of circuit breakers and fuses. It is noteworthy that this has not gone unnoticed by some at Intel, and they are beginning to think that the program has gone too far in scope while others believe just the opposite — thinking that if only every minute aspect of the process could be copied, including gowning procedures, badging procedures, atmospheric pressure, etc. then it would give one greater confidence in achieving identical outputs from different Fabs.

Related to this problem is that skeptics and critics of the program feel that the time and cost associated with implementing the program and its use of technical resources are unwarranted (Myth One) while at the same time the benefits obtained from the program unmeasurable. These skeptics and critics usually support a technology transfer program that is less comprehensive and costly than Copy EXACTLY! These critics are usually silenced by being told that they need to become "team players" by others who believe in the program . Yet no one knows what the overall net cost of the program is nor the net benefits obtained as a result of the use of the program. There has been no attempt at critical examination of the program — just the use of anecdotal evidence that things have gone wrong in the past when Copy EXACTLY! was not followed.

The Copy EXACTLY! program does effectively deal with the Indispensable Researcher Myth {Myth #4}and its corollary in that no single person is the key resource in the technology transfer methodology nor is anyone perceived to be such. The problem with this situation is the difficulty that one faces in trying to define the scope of the program or in resolving issues of conflict and deviation. Discovering who is correct should two or more persons involved in the technology transfer disagree can take many weeks or months. Likewise, obtaining approval for a deviation can take an unduly large amount of time and effort in finding the proper authority and awaiting their decision.

The Copy EXACTLY! program also effectively side steps the issues of Myths Six and Seven. The program cannot even by the wildest stretch of the imagination be viewed as a single element technology transfer program. The information, knowledge and expertise that is transferred from one site to the next is accomplished through a variety of means. Teams of engineers representing all sites involved in the transfer meet to discuss technical and implementation issues. Engineers and manufacturing technicians from the receiving site participate in walk through and inspections of the donating site. Engineers, manufacturing technicians and managers from the donating site complete auditing inspections of the receiving site. There are teams of managers and engineers who give presentations on Copy EXACTLY! and the list goes on.

The Copy EXACTLY! program is an ideal demonstration of how Myth Two can be avoided. Under the concept of this program the transfer of the technology begins well before the end of the development program. Engineers, technicians and managers form the receiving site are brought into the donating site to be trained on the process and equipment that will be used for the manufacturing process. These individuals are also charged with the additional responsibility to learn as much as possible about equipment hookup, preventative maintenance procedures, etc.

The Copy EXACTLY! program also attempts to integrate process improvement into the technology transfer framework at Intel by tying the sister Fabs together for the life of the process technology within that Fab. It is under these circumstances that any process improvement to be made at one of the sister Fabs must be approved and implemented by all of the remaining Fabs unless there is explicit approval for a deviation by the PCCB.

Everyone agrees that incentives and perception of the incentives for an organization must be aligned to the organizational goals. But as figures 3.2.1 - 3.2.6 show, the manufacturing organization at Intel has some significant misalignment in perception of incentives both internally and when comparing themselves with technology development..

Figures 2.4.1-2.4.5 show summary charts of the data collected in Question 1 of Survey B (see Appendix B). There are two surprising conclusions that can be drawn from these data. The first thing that one may notice is the fact that the perception of rewards allocated for certain actions is not consistent across the manufacturing organization. As an example from figure 2.4.1, it can be seen that 36% of the people surveyed believe that personal continuous learning is a factor that is considered when promotion decisions are made. This is a problem no matter how you look at it. One must ask why so many people are getting the wrong message? If personal continuous learning is an important factor in promotions, why does only 36% of the workforce recognize that fact? On the other hand, if personal continuous learning is not an important factor in promotions, why does 36% of the workforce perceive that it is?

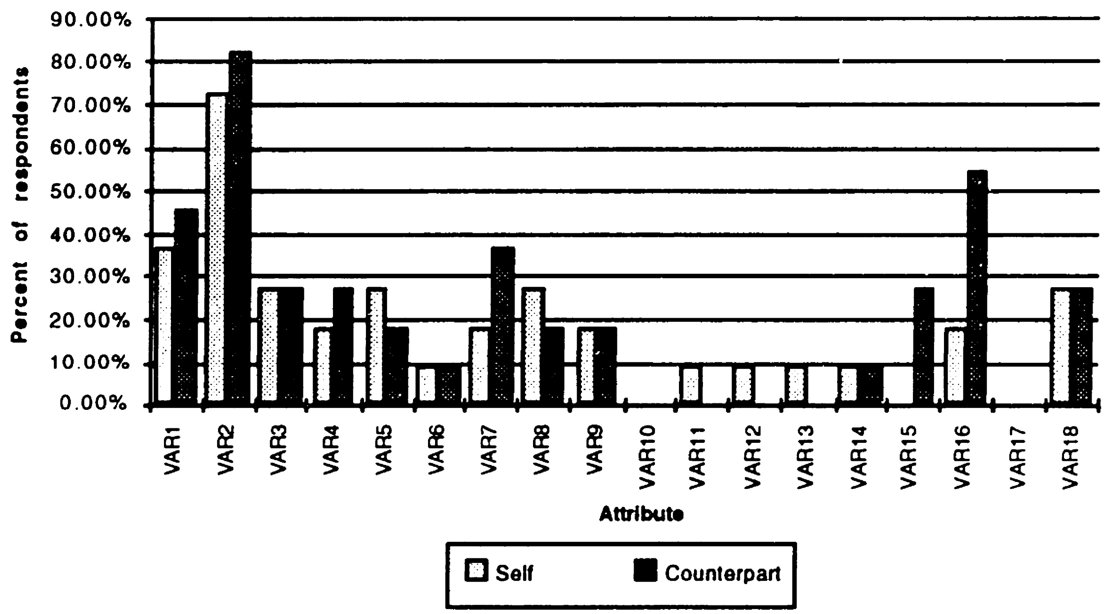


Figure 2.4.1: Percentage of people stating that a certain action was important in obtaining a promotion


Figure 2.4.2: Percentage of people stating that a certain action was important in obtaining a salary increase

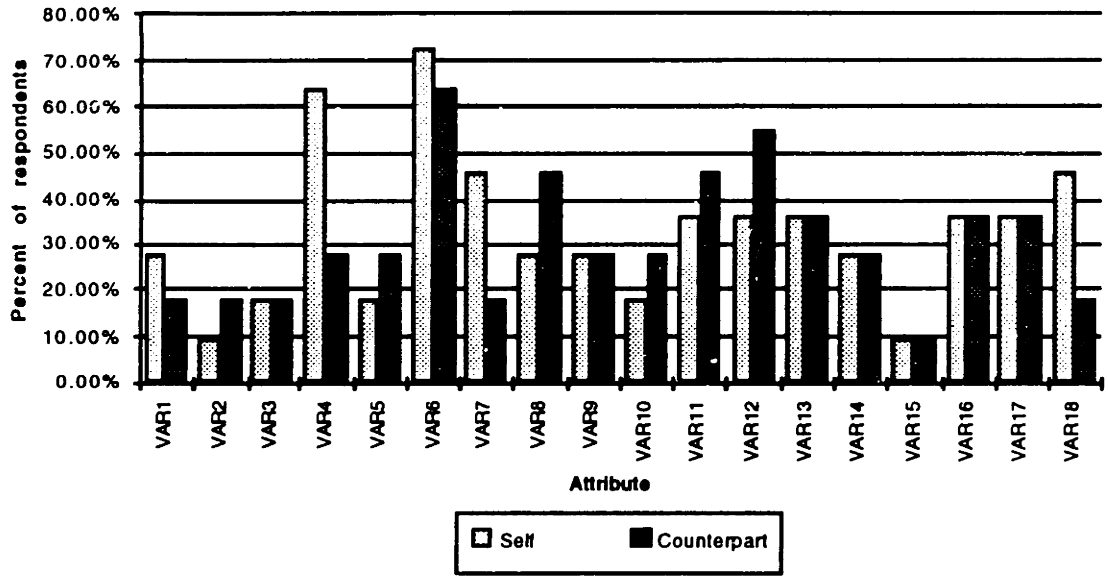


Figure .2.4.3: Percentage of people stating that a certain action was important in obtaining special recognition

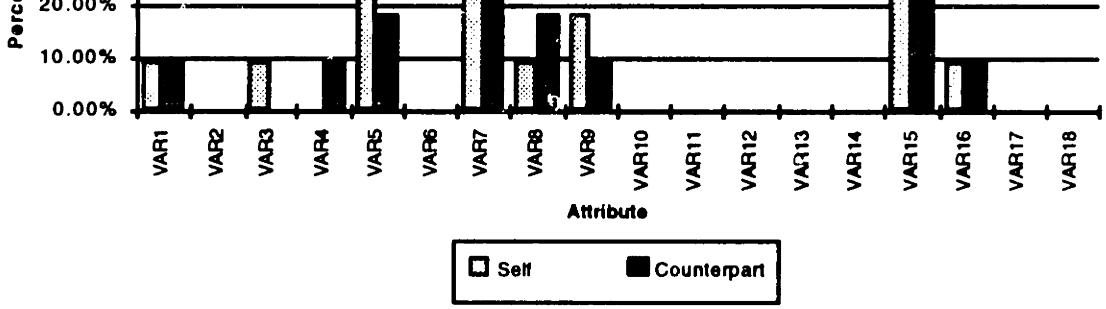


Figure 2.4.4: Percentage of people stating that a certain action was important in obtaining professional recognition inside of Intel

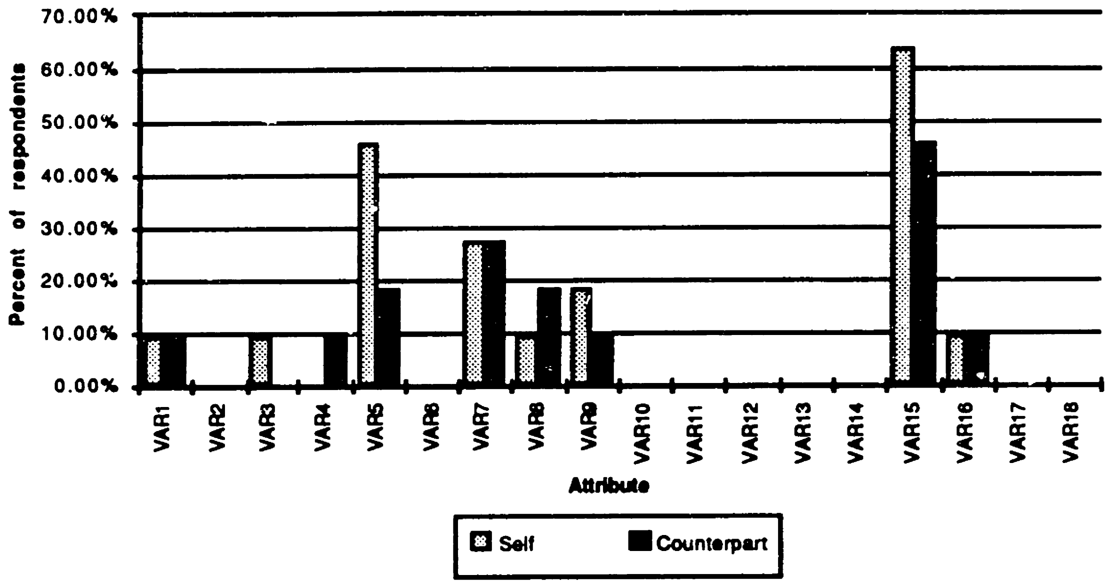


Figure 2.4.5: Percentage of people stating that a certain action was important in obtaining professional recognition outside of Intel

Figures 2.4.6 and 2.4.7 show the aggregate potential reward that it is perceived that an individual may receive for engaging in a particular action. It is important to decide whether the differences that are noted between the perceived reward potential of these actions is actually the priority that senior level management at Intel desires. Another important consideration in this regard is the perception that manufacturing has with respect to the difference between how manufacturing is rewarded and how development is rewarded. The comparison of these two figures demonstrate that not only is there a significant difference in the perceived reward potential between manufacturing and development for an action but also that the distribution of specific rewards for an action is significantly different.

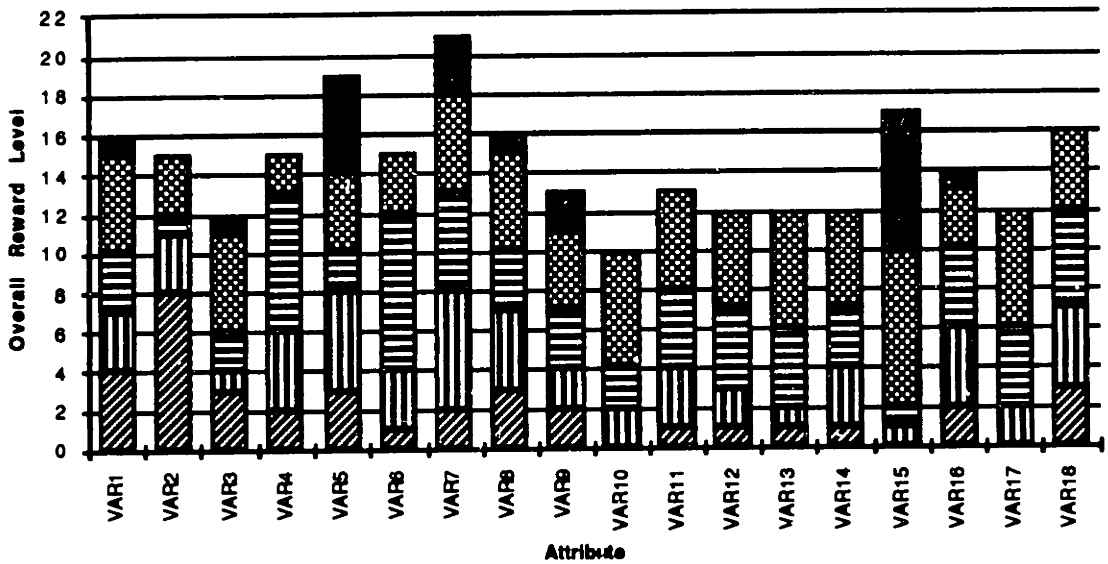


Figure 2.4.6: Perception of total reward potential of a certain action (evaluated for self)

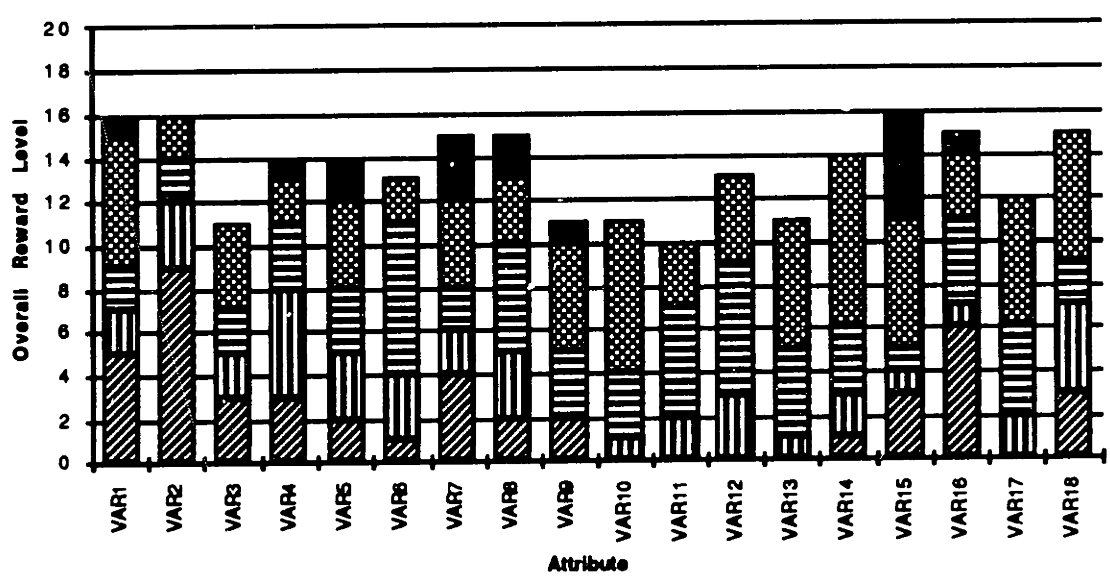


Figure 2.4.7: Perception of total reward potential of a certain action (evaluated for counterpart)

Figure 2.4.8 is a perceptual mapping of the rewards listed in Question 2 of Survey B, evaluated along the dimensions of being either short term or long term rewards. It is interesting to note that those factors perceived most often as long term rewards are factors that have relatively short time horizons for action but possess long term implications on corporate profits. Another interesting observation is that overall — increased visibility within Intel (VAR 7) and being exposed to a different method of accomplishing a task (VAR 8) were not viewed as either long term or short term rewards. Finally, it is interesting to note that no item was viewed overall as only being a long term reward.

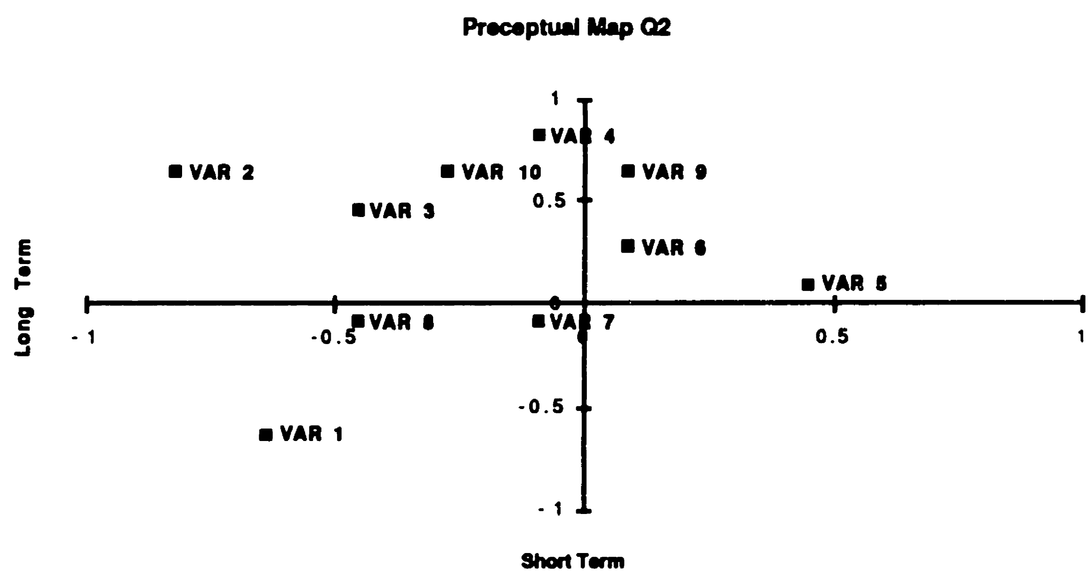


Figure 2.4.8: Short term and long term perception of various rewards

As can be seen in figure 2.4.9 Copy EXACTLY! is perceived as reducing both risk and innovativeness. This result is somewhat disturbing. It appears that the program has achieved one of its goals — that of reducing risk in process technology transfer, but it also seems to have had the effect of reducing the innovativeness of the manufacturing organization. Unless compensating mechanisms are put into place, it may be that the program will allow Intel to complete a successful startup and ramp of a new Fab but then have all of the Fabs that are members of a process' virtual factory fail due to a lack of innovation.

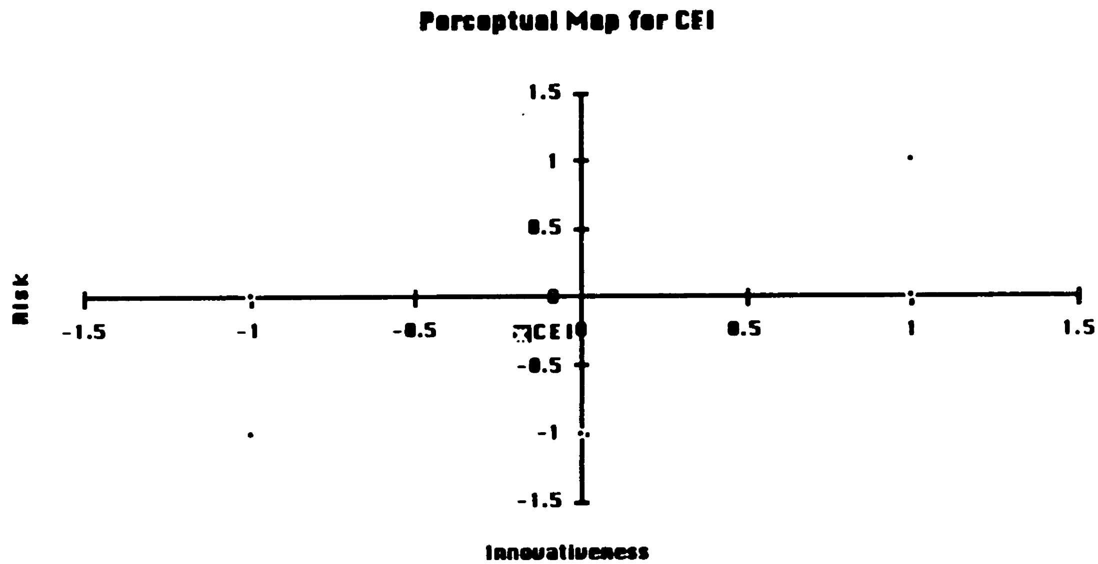


Figure 2.4.9: Perception Copy EXACTLY! in Risk-Innovation space

Figure 2.4.10 shows the percent of surveyed employees at Intel who agree with specific statements made about how the Copy EXACTLY! program is affecting the way in which they work. The engineers and technicians do feel constrained under program when attempting to make process improvements {changes} interactively. However, there is also good agreement among those surveyed that the program also provides them with the ability to more quickly isolate process problems and access to knowledge/feedback in excess of their personal experience.

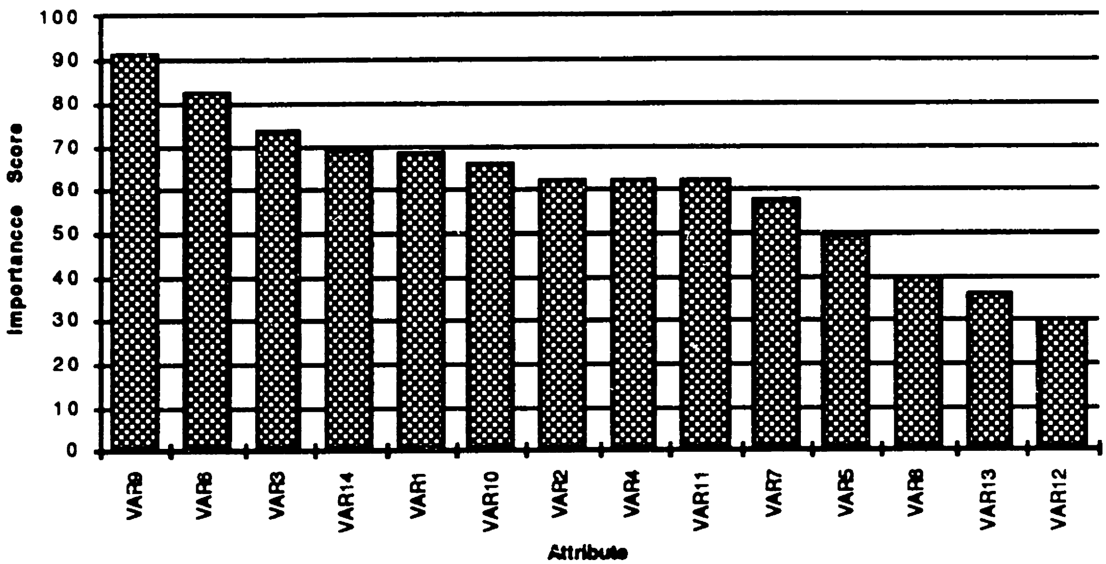


Figure 2.4.10: Percent of people agreeing with statements of Question 9 Survey B

The above perceptual data seem to indicate that the Copy EXACTLY! program, as perceived by the engineers, managers, and technicians, provides significant benefit in the direction of the stated goals of the program; yet this benefit is not without cost. It is imperative that these benefits and costs be quantified in order to determine if the program is of net benefit or not.

## 2.5 Recommendations for Improvement

Figure 2.5.1 shows the importance of various tools, systems, and procedures that need to be developed and implemented in order for Copy EXACTLY! to work as intended. As can be seen from the graph no item received an overall score of less than 50 out of a total of 100. This highlights an important point — the tools, systems and procedures that need to be instituted for the success of the program are perceived to be very broad and inclusive and all of relatively significant importance.

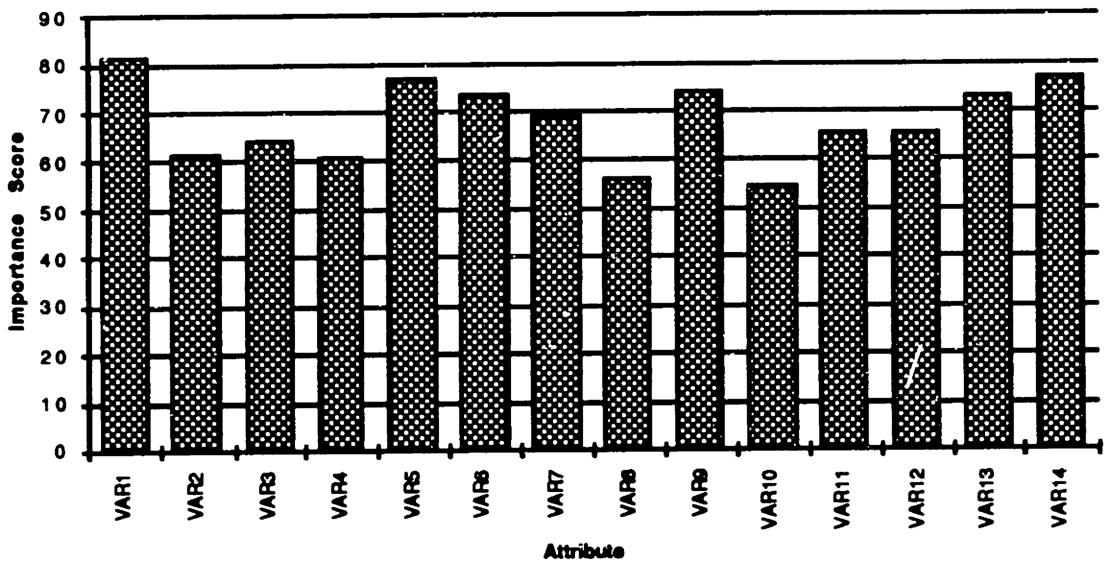


Figure 2.5.1: Rating of tools, systems and procedures needed for Copy EXACTLY![1]

There is a need, particularly among the engineers and technicians that are training at a facility that is not their permanent assignment, for more accurate and complete communication of the training expectations between the home site management and the training site management. More than a few engineers, technicians and managers expressed to me the opinion that the expectations that they had had around the training of off-site engineers and technicians had not been realized. There was high concern that the engineers and technicians were being use as supplemental labor to assist the output performance of the host site to the exclusion of providing adequate training in all areas. This should be tempered with the acknowledgment that not all engineers or technicians felt this way.

[1]Question 8, Survey B

Related to the usage of the allocated time, many of the "guest" engineers and technicians as well as their management felt that the amount of time allocated for training at an operational facility was too short for the average new employee. Therefore Intel should allocate more time for up front training.

Implementation of corporate guidelines on equipment source inspections should also be a high priority item for the senior engineers and managers. The engineers and technicians who conducted on-site and off-site acceptance inspections of process tools had a great deal of freedom in determining many aspects of the inspections of supplier provided equipment. This practice has the potential of allowing multiple process tools of significantly varying performance to be accepted.

Discussions with many of the engineers and technicians concerning the tools and system that they thought were needed to make Copy EXACTLY! work eventually lead to the expression of a desire to have a complete set of on-line process indicators comparison system. These engineers and technicians felt that the system would allow them to better track performance of their operation, module, process, physical Fab, and virtual Fab. Provision of this kind of information would also make many kinds of engineering and business analysis (production forecasting for sort, assembly, and marketing/sales, yield tracking by module, failure analysis, etc.) easier and more realistic.

Training for managers, supervisors and human resource personnel should include sessions or complete programs on how to clearly communicate to another employee the goals and expectations of the corporation and the specific methods that will be used to encourage pursuit and achievement of those goals and expectations.

# CHAPTER 3: Process, Design and Manufacture

## 3.1 The Manufacturing Process

The entire process of fabricating an integrated circuit can be divided into three major groupings. All three of the groupings use one, or more, of the four principles listed on the following pages. These groupings are:

Electrical Components Fabrication

The fabrication of all the electrical components (transistors, capacitors, etc.) needed to make the integrated circuit work property occurs at the beginning, or front-end, of the manufacturing process. In electrical component fabrication, all four principles are used to alter or change the electrical characteristics of specific regions on the water.

Electrical Component Connection

Electrical component connection occurs toward the end, or back-end, of the manufacturing process. All the components created at the front-end of the process are connected with electrically conductive materials, and the wafer is sealed with a protective coating. In electrical component connection only lithography, etch and thin films are used to alter specific regions on the wafer.

Electrical Testing

During electrical testing, the wafer's thickness is reduced by grinding away contaminated backside material. A think layer of chrome/gold is then deposited on the wafer for packaging. Each individual integrated circuit is then tested to verify its functionality before it is sent off for assembly/packaging.

## PRINCIPLES OF IC FABRICATION

The complex structure of an integrated circuit is created by using four basic manufacturing principles. The manufacturing areas within the fabrication facility are divided into the following four functional areas:

Diffusion
Lithography
Etch
Thin Films

The four principles of integrated circuit manufacturing take place in these functional areas. These four basic principles are used repeatedly throughout the manufacturing process, creating multi-layered integrated circuits. These four basic principles are:

### Formation of Thin Layers of Silicon Dioxide

Thins layers of silicon dioxide are placed on the wafer to create insulation between layers of an integrated circuit, and as a protecting agent to stop impurity introduction and etchants from affecting the surface of the wafer. This action is accomplished in the Diffusion and Thin Films areas.

### Introduction of Dopant Atoms (Impurities)

Dopant atoms (or impurities) are introduced into the structure of the silicon wafer to alter or enhance the electrical characteristics of a region. Later in the manufacturing process, these regions are interconnected to create the electrical components (e.g., transistors, capacitors, etc.) of the integrated circuit. This action is accomplished in the Diffusion and Thin Films areas.

Precision Patterning of all Materials on the Wafer's Surface

Precision patterning of the surface of a wafer selectively creates regions with the specific characteristics necessary to form integrated circuits. Initial patterning takes place in a Lithography process, where geometric patterns are created in a photosensitive film placed on the surface of the wafer. Specific regions of the photoresist are then washed away, exposing the underlying material(s). These exposed patterns are then transferred into the underlying structure of the wafer by either etching away material or depositing impurities. This action is accomplished in the Etch, Diffusion and Thin Films areas.

Deposition of Insulating and Conducting Materials

Insulating materials (different from silicon dioxide) are deposited on the wafer to electrically isolate adjacent areas of the circuit. While conducting materials are placed on the wafer to connect the numerous components of the integrated circuit. This conducting material acts as the wiring for the circuit.

Figure 3.1.1 shows how these three areas work together to create integrated circuits.

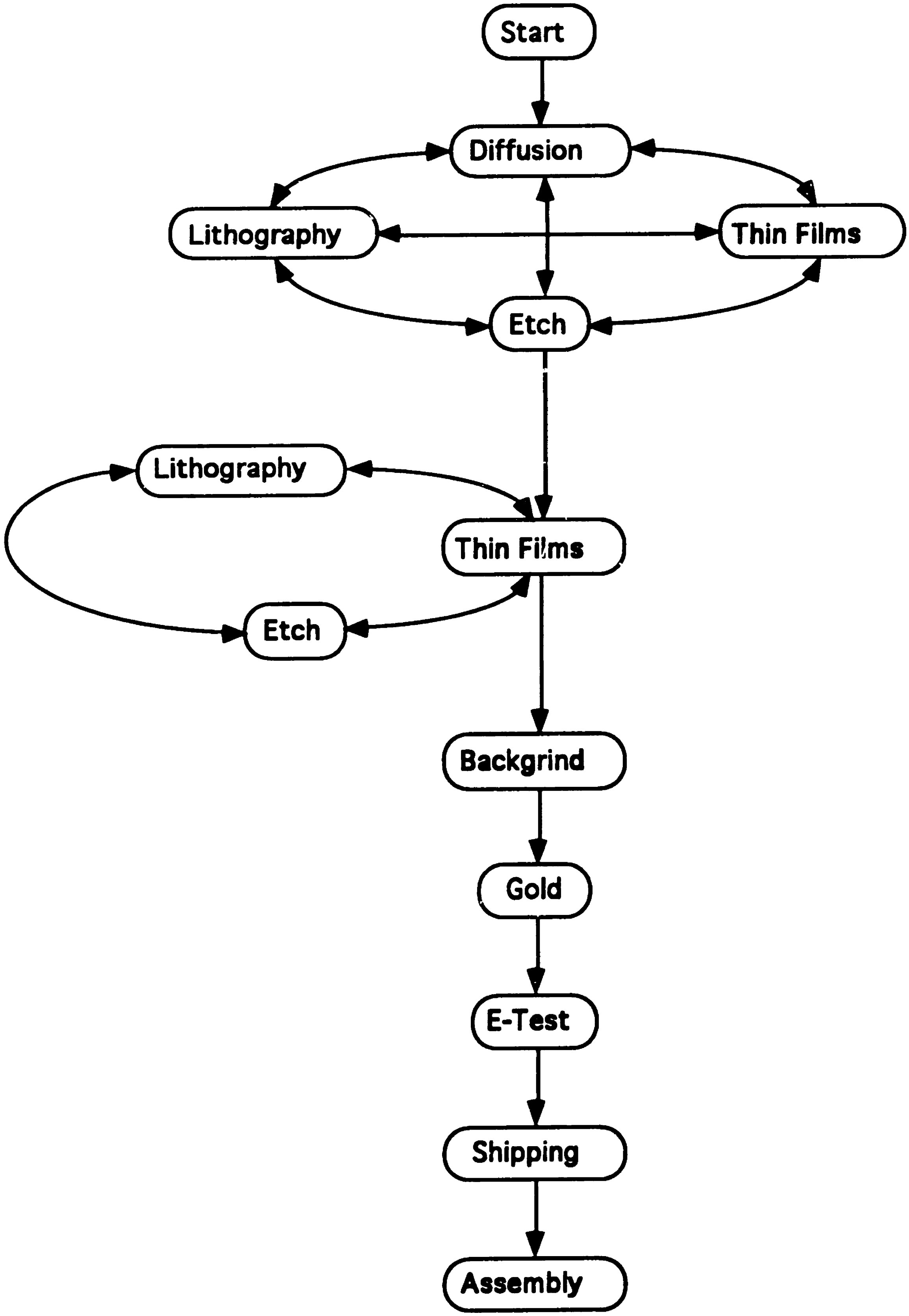


Figure 3.1.1: Typical Process Flow Diagram

## 3.2 What is Manufacturable, Transferable and Sustainable?

In Figure 3.2.1 below, three pairs of models presented as ways of thinking about how research and development and manufacturing interface and interact with one another.

For these models a transferable process (T) is one which is sufficiently mature to the point that the new technology is allowed to be transistioned into a manufacturing facility from a development facility. This definition is somewhat nebulous and uncertain but is a consequence of the usage of the term in that it relies on how one defines a manufacturable process, a sustainable process and how one chooses to allocate the responsibility for achieving these process states. The point of transferability is important because it determines which organization {TD or Manufacturing} is responsible for ensuring that a technology is manufacturable and/or sustainable.

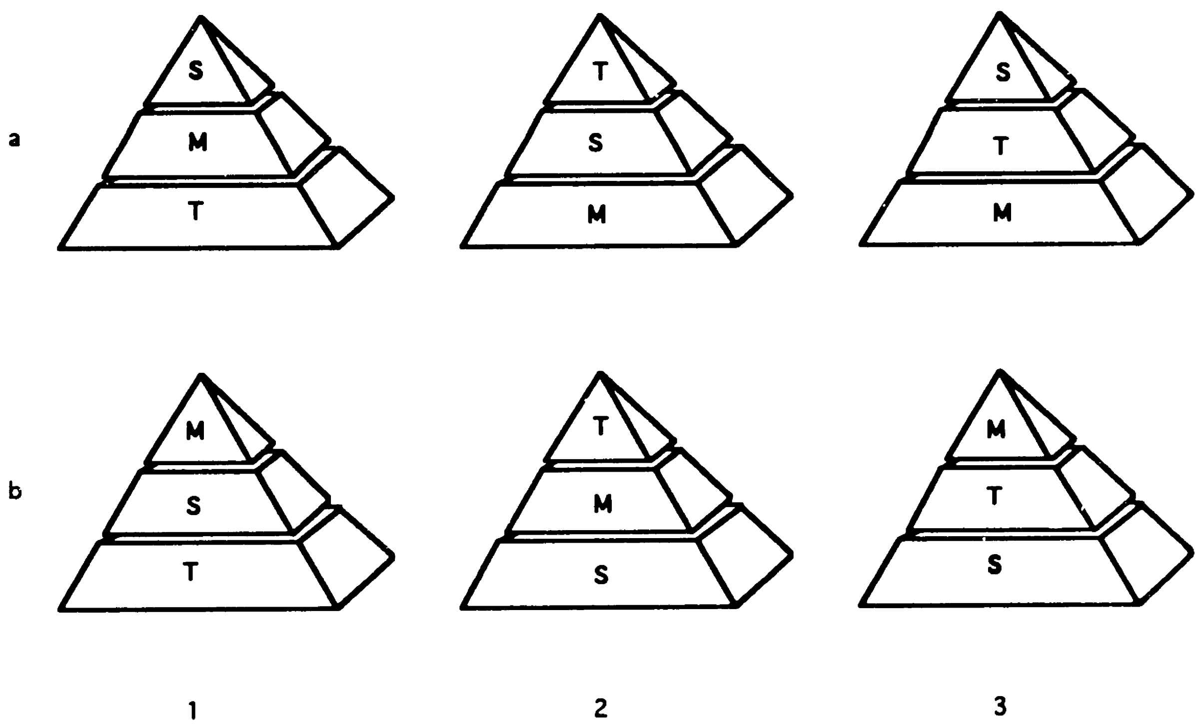


Figure 3.2.1: Hierarchical models of manufacturability, transferability, and sustainability

Models 1a and 1b of Figure 3.2.1 show the old vision of the relationship between manufacturing and research and development. Under these models, technology is transferred to the manufacturing facility (user) without any effort by research & development to do anything more than to assume that the manufacturing facility could actually use the technology. It was then the responsibility of the manufacturing organization to not only meet manufacturing goals, but to recreate process into one that was robust enough for the manufacturing environment. After this was accomplished, the manufacturing organization would then shift into a maintenance mode where no significant improvements would be made to the process/product technology. In this paradigm, manufacturing is burdened with developing or redeveloping a technology so that it works in the company's factories sufficiently well enough to meet corporate goals of profitability. This may well give the manufacturing engineers a good understanding of the technology, but it affords them little time to think about improvements to the technology that may allow the technology to exceed its original goals. This kind of "technology development" is also not occurring at the Research & Development labs as they have more than likely moved on to developing the next generation of technology.

This brings up an important feature of these models — that is the difference between manufacturability and sustainability. All of the models assume either that a manufacturable process state must be attained before a sustainable process state or vice versa. In terms of organizational responsibility, however, it is only within the contexts of the models of 3a and 3b that this difference comes into play. The third possibility of manufacturable process state and a sustainable process state being one and the same would reduce the model set to four {2a & 2b would be eliminated}. Additionally, there would only be two levels within each pyramid rather than the illustrated three as the M and S levels would then be a single level.

The models of 2a & 2b have the development facility fully debug and characterize a new technology before attempting to transfer that technology to a manufacturing facility. Under this paradigm, the Research & Development center engineers would not only need to come up with new technologies and prove feasibility, but they would also need full scale manufacturing facilities personnel and other resources in order to be able to transfer to the manufacturing engineers a technology as if it had "sprung fully grown from the head of Zeus." Under this mode of operation, manufacturing has two possible avenues; either they could accept the technology as a given and run that technology without improvements until the next technology comes along from Technology Development or they could pursue a cause of continuous improvement. The former course, however, begs the question of what to do with the manufacturing engineers that are assigned to manufacturing? More important, however, is the marketplace implications of following this strategy. Not only does the technological innovation stay in development longer, thus reducing corporate profit from the utilization of that technology in their manufacturing operation, but once out of the hands of Technology Development, the technology ceases to improve thus losing any net benefit of incremental improvement. The latter course has the same disadvantage of the former with respect to length of time the technology spends in Technology Development. It does, however, permit the manufacturing engineers to make incremental improvements and the company reaps the benefits.

The models of 3a and 3b are a vision in which the responsibility for the development maturing and incremental improvement of a technology are shared by Research & Development and manufacturing. Since a technology is transferred from development to manufacturing at some point between the two extremes represented by the models 1 & 2, it is under these paradigms that the differences between a manufacturable process state and a sustainable process state become most salient. How an organization chooses to define these words and order their dependency is of great interest to the Research & Development organization and the manufacturing organization because these two decisions more than any others will set the tone of the relationship between the two organizations.

This where Intel is a house divided — there is no consistent set of definitions for manufacturable and sustainable among the engineers, managers and technicians nor is there agreement about what organization should have responsibility for each. Based upon interviews and data collected via survey, the following definitions for manufacturable and sustainable were formulated.

A manufacturable process is one which possesses the following characteristics:

1. has low labor content
2. the process is in control
3. has high factory yields at volume
4. has a $C_{pk} \geq 1.3$ with minimal intervention
5. has all process tools and analytical equipment are characterized
6. is predictable
7. is well documented with respect to statistical performance, process indices, operational procedures, preventative maintenance procedures, specs, and recipes.

A sustainable process is one which possesses the following characteristics:

1. Fully debugged
2. Requires little engineering intervention

3. Trained Manufacturing Technicians

4. Process monitors well understood

5. Centered in large process window

6. Undergoing continuous improvement

7. Meets definition of manufacturable

These definitions explicitly establish the dependency of sustainability on manufacturability. The definitions are appropriate for the Intel operating environment as they are based upon input from Intel manufacturing technicians and engineers in content and reveal the relationship implied by the graphs of figures 3.2.2 and 3.2.3.

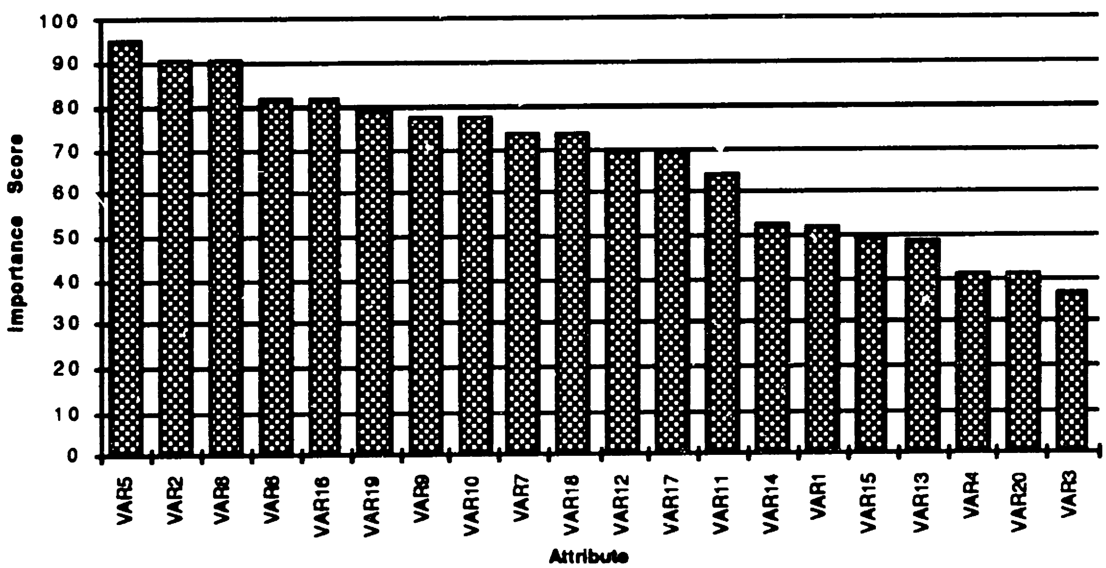


Figure 3.2.2: Rank of items as related to transferability[1]

[1]Question 6, Survey B

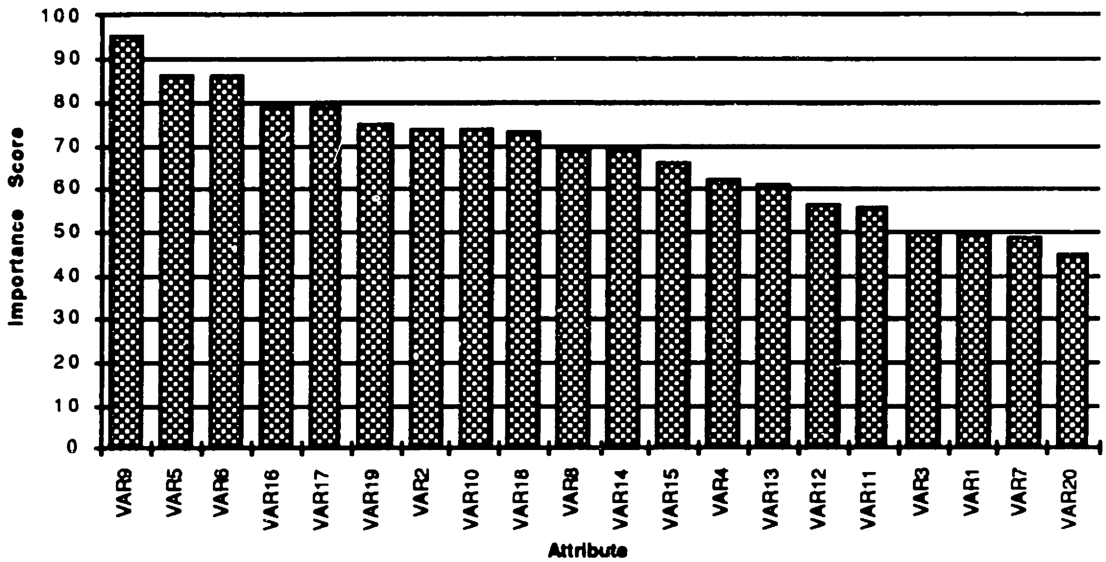


Figure 3.2.3: Rank of items as related to sustainability[2]

## 3.3 Process Design

Intel has chosen reduction of product life cycle as its market strategy. This has made it essential that a new process technology or a new Fab be an unqualified success. This in turn requires that the process/product technology be developed with ease of transfer in mind. A concept that has been called Design for Copy-ability (DFC).

Neither the manufacturing organization nor Intel as a company has a single written collection of rules or guidelines for DFC, therefore, after collecting data from a number of engineers, managers and technicians, the following set of guidelines for copy-ability are recommended.

1. Processes should use as much "off-the-shelf" tooling as possible.

[2]Question 7, Survey B

This may seem counterintuitive, at first, as many companies rely on proprietary equipment or equipment modifications as a source of strategic advantage, this guideline, however, is not meant to be interpreted as "Do not use custom tooling" only that the use of custom tooling should not be undertaken unless there is a clear economic or strategic advantage.

2. A design package should be created as a process is developed.

A design package should be living dynamic document[3] which contains such information and experience as how exactly is a PM procedure performed, what operating characteristics of the tool affect its output and what is that effect. Are there are modifications that have been made to the tool since acceptance from the manufacturer.

## 3.4 What are the Roles of Technology Development and Manufacturing?

Technology development and manufacturing are organizations that are highly dependent on one another. Their interaction both obvious and subtle will make or break one another and the corporation as a whole. Development depends upon manufacturing not only for money, either through direct payment or budgeting from corporate, but also as a source of information on "real-world" manufacturing process issues. Likewise, Manufacturing is dependent upon development as a source of the next process/product technology and as a information source providing expert advice and guidance process reaction physics and chemistry.

[3]The use of the word document is not meant to imply that a design package cannot or should not be electronic based or multi-media based; it is just a convenient shorthand.

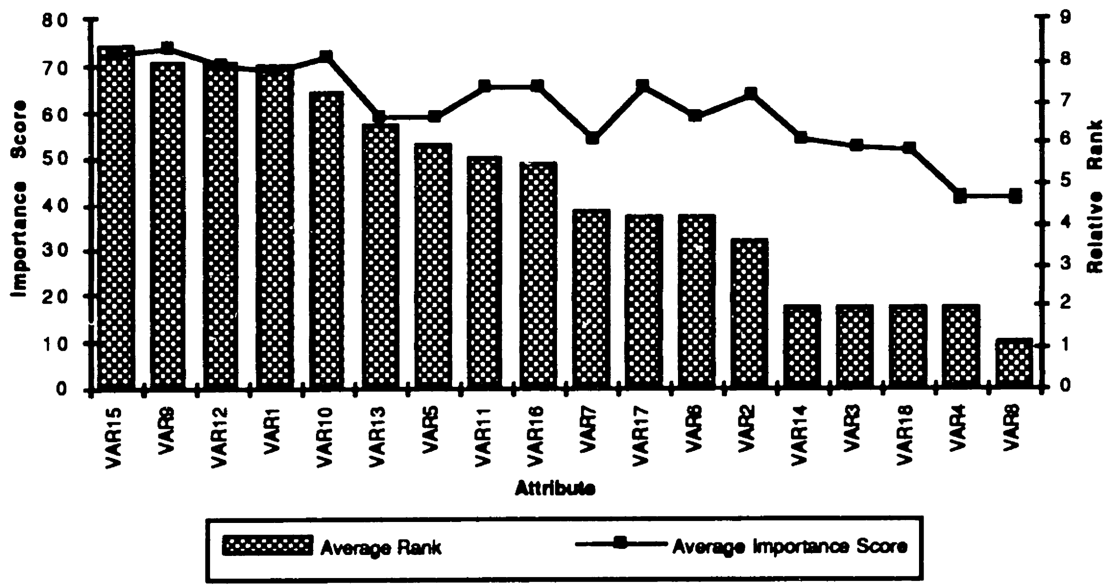


Figure 3.3.1: Rank of items as related to process development[4]

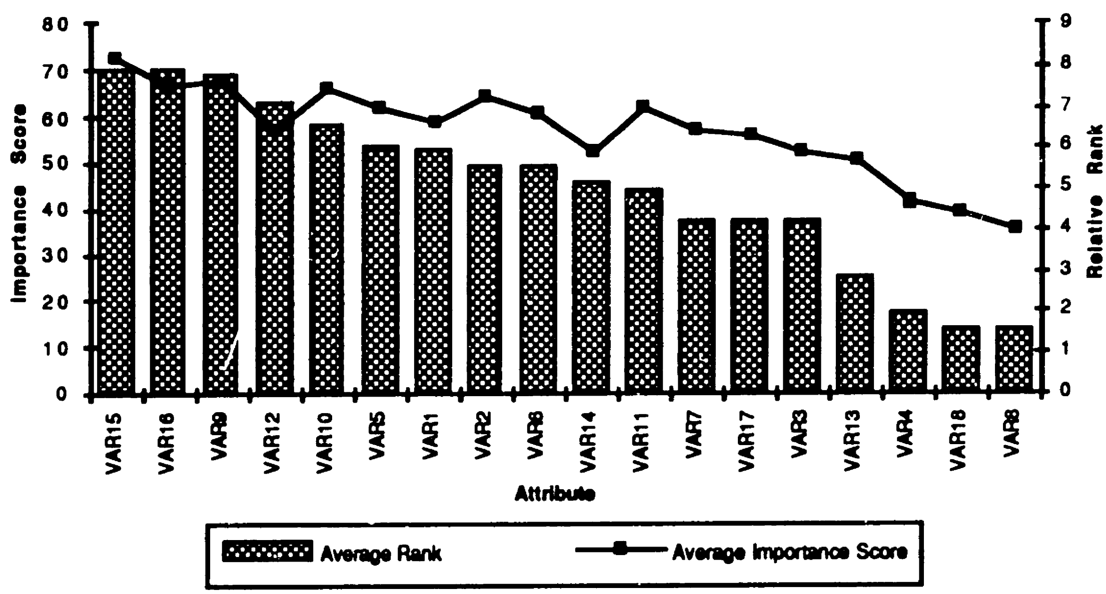


Figure 3.3.2: Rank of items as related to process manufacturing[5]

[4]Question 10, Survey B
[5]Question 11, Survey B

Should these "artificial" divisions of work and expertise be removed so that development engineers and technicians are responsible for manufacturing volume as well as development activities? Should manufacturing engineers also be required to develop new process technology. Intel's answer to these two questions are Yes and No respectively. They believe that the only way or at least the best way to get the development engineers to design a manufacturable process is to make them also responsible for manufacturing to volume specifications.

This course of action seems reasonable given the very plausible reasoning behind it. However, upon deeper examination, one finds several questions that must be answered

1. How do you staff the development organization? Traditionally, development has been staffed with a large number of degrade professionals and a somewhat smaller number of technicians. Where as a manufacturing organization has traditionally been staffed just the opposite — with large numbers of technicians, to run the process, and relatively fewer degreed persons.

2. What is done with the extra personnel either, engineers or technicians, as the organization switches between development and manufacturing? How does one justify the overhead costs?

3. How is expertise among the engineers who must be at the leading edge of technology in order to produce the next process/product design maintained?

4. How do you overcome the cultural biases of the organizations?

It has been shown that manufacturing and development should not only be separate organizations, but also that they must be dedicated to pursuing the goods of their organization. This does not imply that development and manufacturing function in their own vacuums but rather that the relationship between the two be systematized and formalized to ensure the proper and efficient exchange of information, and when appropriate, personnel.

Following this model, the company will realize maximum benefit as it will have a full-time development staff that are experts at new process/product design and technology transfer as well as having manufacturing organizations that are focused on technology transfer, sustaining manufacturing capability and continuos process/product improvement.

# CHAPTER 4: How Should Copy EXACTLY! be Measured?

## 4.1 Success Criteria

The internal measures of success for the Copy EXACTLY! program will be:

1. the reduction in the time-to-market achieved
2. the reduction in ramp time achieved
3. the quality of the output from the Fabs
4. the decrease in cost/unit

ultimately, however, the true measure of the success for the Copy EXACTLY! program will be Intel's performance in the marketplace — all other factors being constant.

I can not even pretend to pretend that I have the insight needed to predict how Intel will fair particularly against such deep-pocketed and talent laden organizations as Apple, International Business Machines, and Motorola (the power PC consortium), Sun Microsystems, and Digital Equipment Corporation. I can on the other hand recommend a tool that may be useful in quantifying the internal measures of success — that tool is the learning curve.[1]

1 Learning Curves are also known in the literature variously as Progress Functions, Progress Curves, Improvement Curves, and Experience Curves.

## 4.2 Learning Curve Theory

In recent years, it has been increasingly recognized that progress functions can be of considerable value in the estimation of production costs, product pricing and the scheduling of labor and equipment. Further, the concept of the progress functions has been incorporated into the main body of economic theory. This has resulted in interesting applications of the progress function concept. It has also provided an important new explanation of technological change in products and services.

Although the learning curve model has achieved this considerable popularity in the airframe industry, a survey of the literature suggests that applications of the concept in other industries have been somewhat narrow and few in number. Past applications have generally been limited to a small number of labor-intensive and labor-paced forms of manufacture that exhibit a high proportion of assembly operations; the manufacture of airframes, machine tools and electronic components are relevant examples. Furthermore, these applications have been focused on only one type of innovation, the introduction of new products or new product models. The usefulness of the concept in describing and estimating the "startups" of new production processes has not been well explored.

The apparent omission of machine-intensive manufacture from past applications of the learning curve concept is somewhat inexplicable, since pronounced and measurable learning phenomena do, in fact, accompany the introductions of new products or production processes in many mechanized forms of manufacture. Words like "startup" and "debugging" are often used to describe the large gains in productivity that are achieved as the personnel in a machine-intensive production system learn how to manufacture a new product or utilize a new production process more efficiently.

If reliable estimates were available, they could be employed usefully in a variety of important planning and control functions in the typical firm. Prior estimation of the productivity gains that attend a startup can reduce materially the levels of uncertainty in such common activities as:

1. Product pricing.
2. Negotiating delivery commitments.
3. Production scheduling.
4. Establishing production standards and wage incentives.
5. Budgeting and cost control.
6. Facility analysis.

It would seem that an extension of the learning curve concept, to include machine-intensive forms of manufacture, would be both intuitively reasonable and pragmatically advantageous.

As organizations produce more of a product, the unit cost of production typically decreases at a decreasing rate. This phenomenon is referred to as a learning curve, a progress curve, an experience curve, or learning by doing. The number of direct labor hours required to assemble a product decreased significantly as experience was gained in production, and the rate of reduction of assembly hours declined with rising cumulative output.

Learning curves have been documented in many organizations, in both the manufacturing and service sectors. The unit costs of producing aircraft, ships, refined petroleum products , and power plants have been shown to follow the characteristic learning-curve pattern. Learning curves have also been found to characterize outcomes as diverse as success rates of new surgical procedures, productivity in kibbutz farming, and nuclear plant operating reliability.

Organizations vary considerably in the rates at which they learn, whereas some organizations show extraordinary rates of productivity growth as cumulative output increases, other fails to show expected productivity gains from learning. Operations that are paced by labor can be expected to have much steeper learning curves than machine paced operation.

The only definitive empirical study done on this topic [machine paced vs. labor paced] was conducted by Hirsch. Hirsch found that machining progress ratios were much smaller than assembly progress ratios. Assembly progress ratios were approximately 2 times larger (25.6 vs. 14.1%) Thus Hirsch's study established that the progress ratio decreases as the proportion of machine-paced labor to total labor

For US. manufacturing and other organizations to compete effectively, we need to understand why some organizations have rapid rates of learning, some learn only slowly and others fail to learn. Thus, we need to identify factors affecting organizational learning curves and use this knowledge to improve manufacturing performance.

Understanding factors affecting learning can enable managers to improve the performance of a firm in many areas. Applications include formulating manufacturing strategy, production scheduling, pricing and marketing, training, subcontracting production, and predicting competitors' costs. The rate and transfer of learning are also important issues for antitrust policy and trade policy.

The conventional form of the learning curve is a power function:

$$Y = KX^n \qquad \text{Eq. (4.1)}$$

$Y$ = the number of direct labor hours required to produce the $x^{th}$ unit

$K$ = the number of direct labor hours required to produce the first unit

$X$ = the cumulative unit number

$n = \frac{\log \Phi}{\log 2}$ = the learning index

$\Phi$ = the learning rate {% curve}

$1-\Phi$ = the progress ratio

As this expression shows, the standard measure of organizational experience in the learning-curve formulation is the cumulative number of units produced, a proxy variable for knowledge acquired through production. If unit costs decrease as a function of this knowledge, other variables being equal, organizational learning is said to occur.

Learning curves are often characterized in terms of a progress ratio, p. With the learning curve in Equation 4.1, each doubling of cumulative output leads to a reduction in unit costs to a percentage, p, of its former value. Thus, an 80% progress ratio means that each doubling of cumulative output leads to a 20% reduction in unit cost.

Care needs to be taken in the application of theoretical learning curve results as Alchian found that fitting learning curves to the aggregate post performance of a single manufacturing facility in order to predict the future could result in a significant margin of error.

At the macroscopic level, the learning curve includes two categories of learning - organizational and labor (personal). Hirschmann claims that the two ways to improve learning lie in the inherent susceptibility of the labor in an operation to improve and the degree to which this susceptibility is explored by the organization.

Interruptions in the Learning Curve (i.e., Relearning)

Interruptions or discontinuities in the learning curve generally occur when new model changes are introduced, the design of the product is changed, or in the case of intermittent production on the same product. These interruptions lead to a learning loss on the part of operators who originally performed the task.

Hall suggests that design changes lead to two costs:

1. The cost of added design less the quoted cost of the design removed.
2. Loss of learning — resulting in not being able to produce an assembly at the full quantity contracted.

Hall focused on a practical way of "factoring in" a new design change into the learning curve after the first unit is produced. Simple graphic techniques are proposed to determine the cost in hours of major design changes. These factors are important to Intel as they introduce new variations within a chip family: Will the performance of the factory be affected? By how much? Is there an optimal strategy for the introduction of change in process or product?

## 4.3 Learning Curves at Intel[2]

In Figures 4.3.1 through 4.3.4 I have shown the learning curves for Intel's P411.3 and P648 processes at Intel's Fab 4, Fab 7, Fab 8 and Fab 9. Additionally on each plot will be

[2]These learning curves are based on wafer cost as a function of cumulative wafer production.

found a curve that represents a standard learning curve based on the same periodic and cumulative wafer production as the actual curve.

Examination of the correlation coefficients for figures 4.3.1 through 4.3.4 reveal a trend of increasing learning within Intel with the exception of the correlation coefficient for the P648 process in Fab 9. These results, in general, are very encouraging for the aspect of seeking organizational learning and the resultant benefits. The reason for the smaller correlation coefficient for Fab 9 P648 needs to be investigated in order to determine if this is just an artifact of the data collected and used or whether it is due to some other cause.

| | | | |
|---|---|---|---|
| % curve = | 0.93 | Lrn rate = | -0.10 |
| $\chi^2$ = | 1.185 | $R^2$ = | 0.00184 |

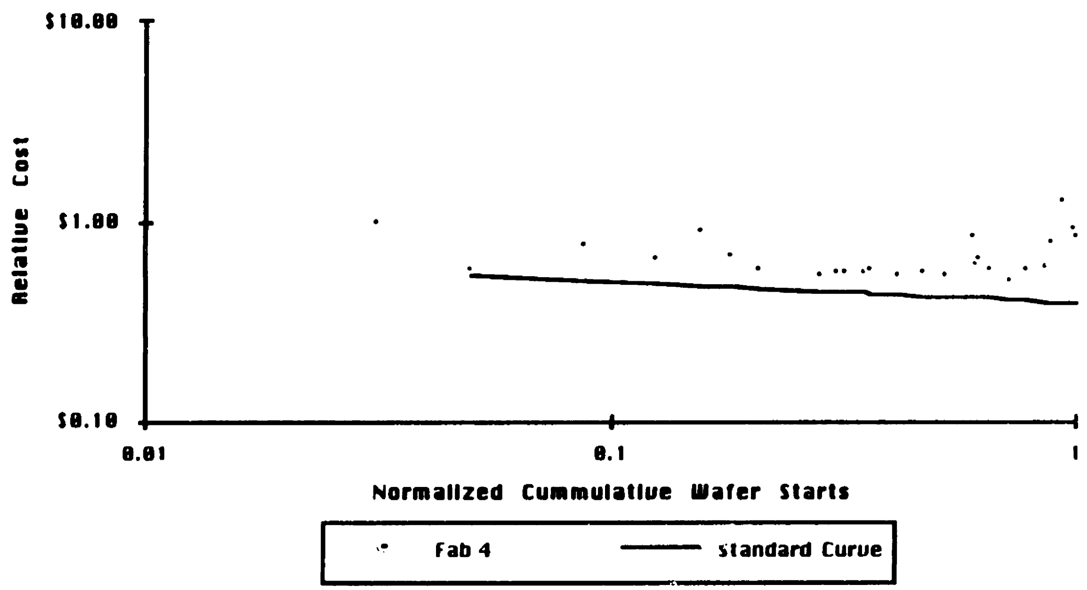


Figure 4.3.1: Fab 4 P411.3 Learning curve

| | | | |
|---|---|---|---|
| % curve = | 0.95 | Lrn rate = | -0.07 |
| $\chi^2$ = | 2.59 | $R^2$ = | 0.07497 |

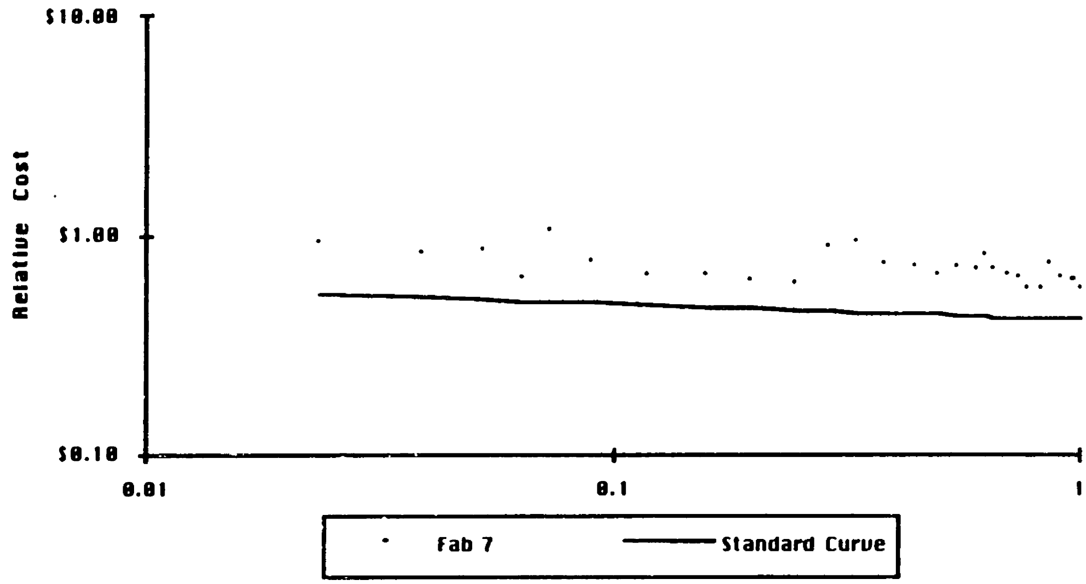


Figure 4.3.2: Fab 7 P648 Learning curve

| | | | |
|---|---|---|---|
| % curve = | 0.95 | Lrn rate = | -0.07 |
| $\chi^2$ = | 1.28 | $R^2$ = | 0.13116 |

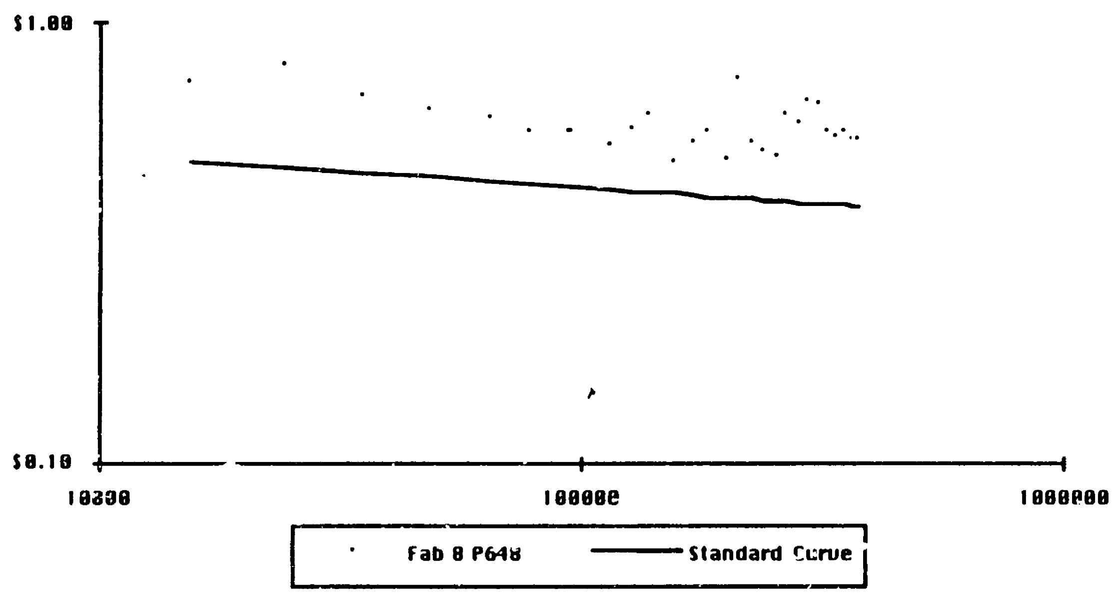


Figure 4.3.3: Fab 8 P648 Learning curve

| | | | |
|---|---|---|---|
| % curve = | 0.95 | Lrn rate = | -0.07 |
| $\chi^2$ = | 16.36 | $R^2$ = | 0.002557 |

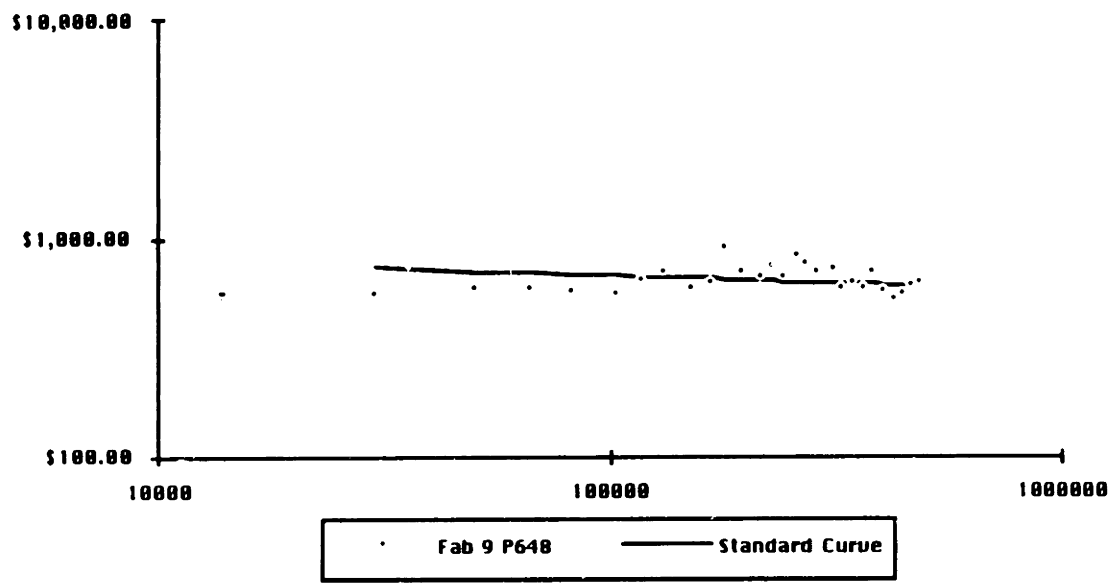


Figure 4.3.4: Fab 9 P648 Learning curve

In Figures 4.3.5 and 4.3.6 I have shown the learning curves for Intel's P650 process at Intel's Fab 8 and Fab 9, respectively. Additionally on each plot will be found a curve that represents a standard 20% learning curve based on the same periodic and cumulative wafer production as the actual curve. As can be seen visually the two Fab learning curves match quite well to the standard learning curve. Moreover, statistical analysis of the actual data points and samples of the theoretical learning curves show strong a correlation between the actual learning curve and the theoretical learning curve. Therefore it is possible that the cumulative volume of wafer production may be a reasonable indicator of learning.

| | | | |
|---|---|---|---|
| % curve = | 0.75 | Lrn Rate | -0.4150 |
| $\chi^2$ = | 3.7199 | $R^2$ = | 0.10163 |

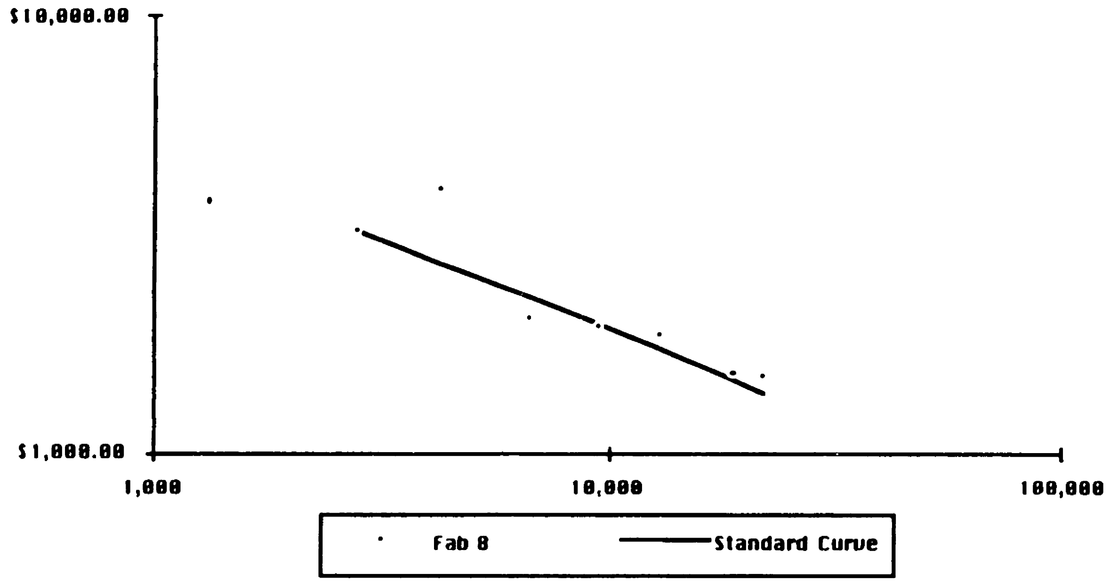


Figure 4.3.5: Fab 8 P650 Learning curve

| | | | |
|---|---|---|---|
| % curve = | 0.75 | Lrn Rate = | -0.4150 |
| $\chi^2$ = | 8.2162 | $R^2$ = | 0.33090 |

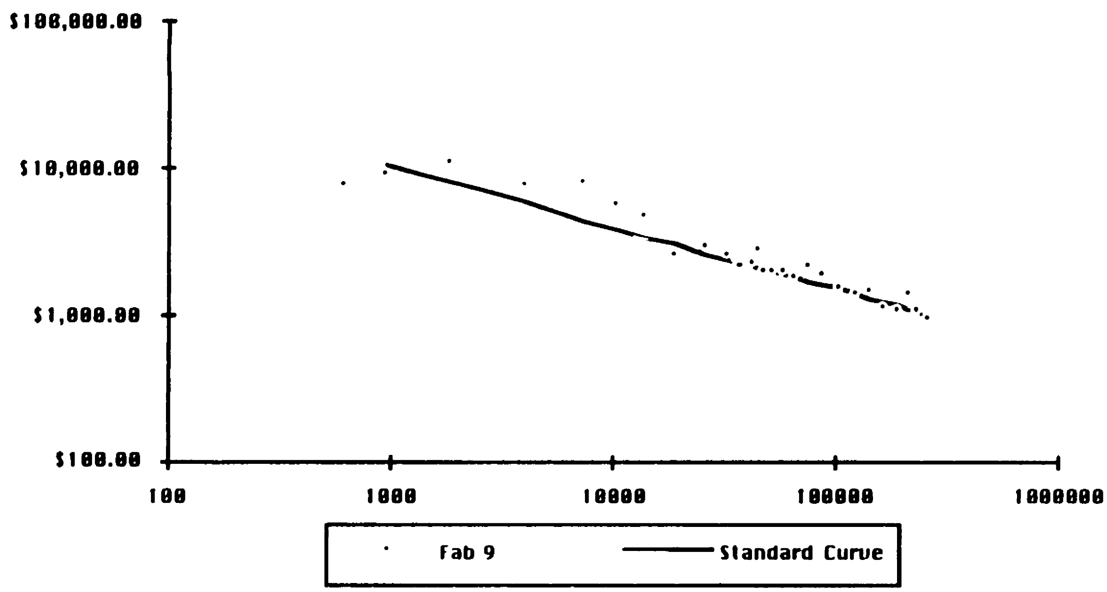


Figure 4.3.6: Fab 9 P650 Learning curve

# Future Work

The research presented herein has provided insight into Copy EXACTLY! and technology transfer. It has examined the underlying structural design of technology transfer programs and some common myths surrounding them that need to be addressed in order for a technology transfer program to have a greater chance of success. Also, internal and external measures of success for Copy EXACTLY! and a tool for quantifying the internal success factors has been recommended.

Copy EXACTLY! as a corporate commitment is evolving at Intel. Whether it becomes a passing phase or a corporate cornerstone will depend largely upon the perceived value derived from the program in light of its unquantified but potentially enormous cost in terms of human and financial resources.

Additional work is needed in this area to quantify the costs and benefits o the program. Specifically Intel needs to:

1. Quantify the financial and non-financial costs of Copy EXACTLY!

2. Explore the other measures of organizational learning that may be useful or informative in analyzing the performance of a Fab over time. This may include analyses such as EDO/Cumulative wafer starts or Cost/EDO.

3. Systematically study the impact of the program on personnel motivation which is well correlated with individual innovation.

**Questions for Managers**

1. What is your title?

2. What are your functional responsibilities?

3. a) How long have you worked at Intel?
   b) Have you worked anywhere else?

4. a) Have you participated in Copy EXACTLY! before?
   b) Have you participated in any other technology transfer programs?

5. What kinds of effects has Copy EXACTLY! had on the way you do business?

6. What kinds of effects will Copy EXACTLY! have on the way you do business?

7. What do you see as the future of Copy EXACTLY! ?

8. How important is Copy EXACTLY! to the success of Intel?

9. What are the goals of Copy EXACTLY! ?

10. What are the alternatives to Copy EXACTLY! ?

11. HAve any of the alternatives to Copy EXACTLY! been evaluated?

12. Who would you recommend as interviewees for the Copy EXACTLY! process evaluation?

Process Engineers Technicians

13. Who would you recommend as contacts for learning more about the process and equipment running in the FAB?

D E F E    1 2 3 4 5 6 7 8 9 0

intel.

# Copy EXACTLY!

## Survey

Massachusetts Institute of Technology
LEADERS FOR MANUFACTURING PROGRAM

Eric Sebastian Fears
Leaders for Manufacturing Fellow

1. Listed below are a set of rewards, each identified by a letter preceding it:

a. promotions
b. salary increases
c. special recognition
d. professional recognition inside Intel
e. professional recognition outside Intel

A. This section asks you to identify which rewards you hope to receive for certain tasks/behaviors. For each task/behavior circle the letter corresponding to all the rewards that you expect to receive for that task/behavior.

| | |
|---|---|
| VAR 1 | Personal continuous learning |
| VAR 2 | Leadership skills |
| VAR 3 | Meeting commitments |
| VAR 4 | Above average work quality |
| VAR 5 | Formal Education |
| VAR 6 | Safety record |
| VAR 7 | Generating patentable ideas |
| VAR 8 | Displaying a good work attitude |
| VAR 9 | Ability to communicate clearly |
| a b c d e | Other: ________________ |

| | |
|---|---|
| VAR 10 | Good attendance |
| VAR 11 | Reducing resources used in production |
| VAR 12 | Involvement in problem solving |
| VAR 13 | Team orientation and participation |
| VAR 14 | Visibility of project / activity |
| VAR 15 | Publishing papers |
| VAR 16 | Placing work before personal life |
| VAR 17 | Attitude displayed toward other employees |
| VAR 18 | Reducing defects |
| a b c d e | Other: ________________ |

B. This section asks you to identify which rewards you believe that your counterpart receives for certain tasks/behaviors. For each task/behavior circle the letter corresponding to all the rewards that you believe he or she receives for that task/behavior.
(Counterpart means: if you are in manufacturing consider someone who has a job similar to yours in development or if you are in development consider someone who has a job similar to yours in manufacturing)

| | |
|---|---|
| VAR 1 | Personal continuous learning |
| VAR 2 | Leadership skills |
| VAR 3 | Meeting commitments |
| VAR 4 | Above average work quality |
| VAR 5 | Formal Education |
| VAR 6 | Safety record |
| VAR 7 | Generating patentable ideas |
| VAR 8 | Displaying a good work attitude |
| VAR 9 | Ability to communicate clearly |
| a b c d e | Other: ________________ |

| | |
|---|---|
| VAR 10 | Good attendance |
| VAR 11 | Reducing resources used in production |
| VAR 12 | Involvement in problem solving |
| VAR 13 | Team orientation and participation |
| VAR 14 | Visibility of project / activity |
| VAR 15 | Publishing papers |
| VAR 16 | Placing work before personal life |
| VAR 17 | Attitude displayed toward other employees |
| VAR 18 | Reducing defects |
| a b c d e | Other: ________________ |

2 For this question you are to place an S next to each item you consider to be a short term professional reward for you for using Copy EXACTLY! and place an L next to each item you consider to be a long term professional reward for you for using Copy EXACTLY! (Note: An item can be can be a long term reward, a short term reward, both a long and short term reward, or neither a long term or short term reward)

| | |
|---|---|
| VAR 1 | No rewards for using Copy Exactly! |
| VAR 2 | Increased responsibility within Intel. |
| VAR 3 | Increased potential to relocate to other sites using the same process. |
| VAR 4 | Increased profitability of Intel. |
| VAR 5 | Reduction of number of problems in fab startup. |
| | Other:_______________ |

| | |
|---|---|
| VAR 6 | Achieving same ISO as original fab. |
| VAR 7 | Increased visibility within Intel. |
| VAR 8 | Exposure to a different method of accomplishing a task. |
| VAR 9 | Ability to match process indicators. |
| VAR 10 | Reduction in the number of problems in sustaining a fab. |
| | Other:_______________ |

3. Describe what is meant by saying a process is a transferable process?

4. Describe what is meant by saying a process is a manufacturable process?

5. Describe what is meant by saying a process is a sustainable process?

For Questions 6, 7, 8, 9, 10 and 11 you will be asked to rate items by a relative importance scale This scale has three (3) levels in it Items rated as A (critical) should be "must have" items without which it would be impossible to complete the activity in question Items rated as B (important) should be items which substantially reduce the resources required to complete the activity in question but are not critical Items rated as C (nice to have) should be items which reduce the resources required to complete the activity in question but are not as important as items rated as B

6. Consider what are the items that you feel make a process transferable? Rate the importance of the items in the following table. You may write in and rate up to two (2) additional items in the spaces provided.
( A = critical, B = important, C = Nice to have)

| | |
|---|---|
| VAR 1 | Having well defined common goals among different sites. |
| VAR 2 | Having accurate specs. |
| VAR 3 | Having a process that is not specific to a single machine. |
| VAR 4 | Having supplier involvement to improve equipment utilization. |
| VAR 5 | Having well characterized equipment. |
| VAR 6 | Having a process in which interactions are well understood. |
| VAR 7 | Having well defined common goals at a particular site. |
| VAR 8 | The discipline of the transferring organization in following specifications. |
| VAR 9 | Having a stable process. |
| VAR 10 | Having a well documented process. |
| | Other:________________ |

| | |
|---|---|
| VAR 11 | Clear communication of expectations between different organizations. |
| VAR 12 | Having a process that is not site specific. |
| VAR 13 | Having specs which do not require frequent operator intervention. |
| VAR 14 | Having supplier involvement to improve equipment uptime. |
| VAR 15 | Having a large process latitude |
| VAR 16 | The discipline of the receiving organization in following specifications. |
| VAR 17 | Clear communication of expectations by management. |
| VAR 18 | Having all equipment and supplies being readily available. |
| VAR 19 | Having well defined specs. |
| VAR 20 | Having a work force whose primary goal in life is to achieve the company's goals. |
| | Other:________________ |

7 Consider what are the items that you feel make a process sustainable? Rate the importance of the items in the following table. You may write in and rate up to two (2) additional items in the spaces provided.
( A = critical, B = important, C = Nice to have)

| | |
|---|---|
| VAR 1 | Having well defined common goals among different sites. |
| VAR 2 | Having accurate specs. |
| VAR 3 | Having a process that is not specific to a single machine. |
| VAR 4 | Having supplier involvement to improve equipment utilization. |
| VAR 5 | Having well characterized equipment. |
| VAR 6 | Having a process in which interactions are well understood. |
| VAR 7 | Having well defined common goals at a particular site. |
| VAR 8 | The discipline of the transferring organization in following specifications. |
| VAR 9 | Having a stable process. |
| VAR 10 | Having a well documented process. |
| | Other:________________ |

| | |
|---|---|
| VAR 11 | Clear communication of expectations between different organizations. |
| VAR 12 | Having a process that is not site specific. |
| VAR 13 | Having specs which do not require frequent operator intervention. |
| VAR 14 | Having supplier involvement to improve equipment uptime. |
| VAR 15 | Having a large process latitude |
| VAR 16 | The discipline of the receiving organization in following specifications. |
| VAR 17 | Clear communication of expectations by management. |
| VAR 18 | Having all equipment and supplies being readily available. |
| VAR 19 | Having well defined specs. |
| VAR 20 | Having a work force whose primary goal in life is to achieve the company's goals. |
| | Other:________________ |

9. Consider how Copy EXACTLY! is affecting the way in which you work. Rate the importance of the items in the following table. ( A = critical, B = important, C = Nice to have) You may write in and rate up to two (2) additional items in the spaces provided.

| | |
|---|---|
| VAR 1 | It causes me to more carefully scrutinize process modifications.. |
| VAR 2 | It requires the microscopic examination of process/equipment as well as macroscopic examination. |
| VAR 3 | It helps me in finding process problems more quickly. |
| VAR 4 | It focuses/organizes the content of my work |
| VAR 5 | It ties my hands to making improvements |
| VAR 6 | It limits my ability to make changes "on-the-fly". |
| VAR 7 | It increases my team orientation. |
| | Other: |

| | |
|---|---|
| VAR 8 | I repeat procedures without regard to professional or personal insight. |
| VAR 9 | I have available to me feedback/knowledge from a greater range of experience. |
| VAR 10 | It makes me observe what is actually done rather than relying on specs. |
| VAR 11 | It increases the scope of my work. |
| VAR 12 | It limits my creativity |
| VAR 13 | I don't look for improvements, I just copy the existing equipment/process. |
| VAR 14 | Increases my ability to network. |
| | Other: |

8. Consider what are the things that must be developed in order to make Copy EXACTLY! work as intended. Rate the importance of the items in the following table. You may write in and rate up to two (2) additional items in the spaces provided.
( A = critical, B = important, C = Nice to have)

| | |
|---|---|
| VAR 1 | Cross site specification teams. |
| VAR 2 | Process synergy reviews. |
| VAR 3 | Cross site users groups that include suppliers. |
| VAR 4 | Increased communication between management at different sites. |
| VAR 5 | Accurate and complete communication of training expectations between home site management and training site management. |
| VAR 6 | Communication between teams. |
| VAR 7 | Progress/status reports. |
| | Other:________ ____________ |

| | |
|---|---|
| VAR 8 | Increased training time. |
| VAR 9 | Shared specs. |
| VAR 10 | Increased communication between managers and non-managers. |
| VAR 11 | On-line process indicators comparison system. |
| VAR 12 | Exchange of personnel between sites. |
| VAR 13 | Consistent methods of source inspection. |
| VAR 14 | Common ISO goals. |
| | Other:________________ |

10. The next section asks you to determine the relative value of various systems, procedures and tools as they relate to process development.

A. Assuming that you have <u>limited</u> time and money to spend on the items listed in the table below, prioritize them according to value in process development. ( A = critical, B = important, C = nice to have) You may write in and rate up to two (2) additional items in the spaces provided.

**NO MORE THAN 5 ITEMS MAY BE RATED AS A**

**NO MORE THAN 5 ITEMS MAY BE RATED AS B**

B. **In the shaded area indicate the importance of the item to process copyability** (i.e. ease of producing similar output at another site without the need for extensive process redesign/redevelopment)

| | A Rank | |
|---|---|---|
| Analytical Equipment | VAR 1 | |
| Consistent Sampling Plans | VAR 2 | |
| Consistent dispositioning methods | VAR 3 | |
| Equipment Layout | VAR 4 | |
| Process Improvements | VAR 5 | |
| Equipment Improvements | VAR 6 | |
| Operational Improvements (measurement procedures, etc. ) | VAR 7 | |
| Automated Material Handling System | VAR 8 | |
| Clean room environment | VAR 9 | |
| Materials (gases, chemicals, etc.) | VAR 10 | |
| Consistent SPC limits | VAR 11 | |
| Preventative Maintenance Procedures | VAR 12 | |
| Installation methods | VAR 13 | |
| Workstream Model | VAR 14 | |
| Specifications | VAR 15 | |
| Consistent Process change validation | VAR 16 | |
| Sequential testing for tool matching | VAR 17 | |
| Other Computer Aided Manufacturing Tools | VAR 18 | |
| other: | | |
| other: | | |

11 The next section asks you to determine the relative value of various systems, procedures and tools as they relate to process manufacturing.

A. Assuming that you have **limited** time and money to spend on the items listed in the table below, prioritize them according to value in process manufacturing. ( A = critical, B = important, C = nice to have) You may write in and rate up to two (2) additional items in the spaces provided.

**NO MORE THAN 5 ITEMS MAY BE RATED AS A**

**NO MORE THAN 5 ITEMS MAY BE RATED AS B**

B. In the shaded area indicate the importance of the item to process reproducibility (i.e. consistently producing similar output without the need for frequent operator intervention)

| | A Rank | B [illegible] |
|---|---|---|
| Analytical Equipment | VAR 1 | |
| Consistent Sampling Plans | VAR 2 | |
| Consistent dispositioning methods | VAR 3 | |
| Equipment Layout | VAR 4 | |
| Process Improvements | VAR 5 | |
| Equipment Improvements | VAR 6 | |
| Operational Improvements (measurement procedures, etc. ) | VAR 7 | |
| Automated Material Handling System | VAR 8 | |
| Clean room environment | VAR 9 | |
| Materials (gases, chemicals, etc.) | VAR 10 | |
| Consistent SPC limits | VAR 11 | |
| Preventative Maintenance Procedures | VAR 12 | |
| Installation methods | VAR 13 | |
| Workstream Model | VAR 14 | |
| Specifications | VAR 15 | |
| Consistent Process change validation | VAR 16 | |
| Sequential testing for tool matching | VAR 17 | |
| Other Computer Aided Manufacturing Tools | VAR 18 | |
| other: | | |
| other: | | |

12. Rank in order of importance under Copy EXACTLY! the following issues:
**(THERE CAN BE NO TIES,** 1 = most important)

VAR 1 delivering product as promised
VAR 2 reducing the time to ramp to volume production
VAR 3 allowing Intel to source product as it wishes
VAR 4 encouraging employees to be innovative
VAR 5 meeting Fab performance criteria (Fab indicator targets)
VAR 6 minimizing total cost of manufacturing a product
VAR 7 maximizing the quality of the product

13. What effect does Copy EXACTLY! have on innovativeness and risk taking?
**CHECK ONE ONLY.**

_______ No effect on innovativeness or risk taking.
_______ No effect on innovativeness and decreases risk taking.
_______ No effect on innovativeness and increases risk taking.
_______ Decreases innovativeness and no effect on risk taking.
_______ Decreases innovativeness and increases risk taking.
_______ Decreases both innovativeness and risk taking.
_______ Increases innovativeness and no effect risk taking.
_______ Increases innovativeness and decreases risk taking.
_______ Increases both innovativeness and risk taking

14. In the Table below:

A. Rank in order of importance the goals of the Copy EXACTLY! program.

**THERE CAN BE NO TIES, DO NOT RANK ITEMS THAT YOU WRITE IN THE "OTHER" BLANKS**

(1 = most important)

B. In the shaded area indicate how well do you think the Copy EXACTLY! program meets these goals?

| | A<br>RANK | B<br>[illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|
| Reducing time to ramp to volume | | | | | | |
| Producing identical performance chips | | | | | | |
| Creating Synergy | | | | | | |
| Reducing risks in process transfer | | | | | | |
| Producing same ISO/Quality (yield) levels | | | | | | |
| Creating Shared Learning | | | | | | |
| other: | | | | | | |
| other: | | | | | | |

15. Why use Copy EXACTLY! if there is a clear and measurable benefit in changing a process step or procedure?

16 Circle the one term that best describes your occupation: Manufacturing Technician | Engineer | Manager

17 Circle the facility that is your home site: D2 | EP1 | F10

18. Circle the one area in which your job functions primarily fall.

a. installations/qualifications
b. sustaining/improvement
c. technology development

19. Circle the one functional area of which you are a member or with which you most closely identify?

a. Thin Films
b. Diffusion
c. Sort
d. Etch
e. Lithography
f. Yield Engineering

20. How long (in years and months) have you worked in the semiconductor industry? ☐☐ Years ☐☐ Months

21. How long (in years and months) have you worked for Intel? ☐☐ Years ☐☐ Months

22. How long (in years and months) have you been at your current position at Intel? ☐☐ Years ☐☐ Months

Copy EXACTLY! Project questionaire

What facility are you working at?

What facility is your home site?

Are you involved in operations, training, installations, sustaining/improvement or development?
(What is your job?)

What is the functional area of which you are a member?

- Thin Films
- Diffusion
- Sort
- Maintainence
- Etch
- Training

How long have you worked for Intel?

How long have you been at your current position?

Rank in order of importance for the goals of the Copy EXACTLY! program. ( 1 = most important, there can be no ties) Also indicate how well do you think the Copy EXACTLY! program meets these goals?

| | | very unsatisfactory | somewhat unsatisfactory | neutral | somewhat satisfactory | very satisfactory |
|---|---|---|---|---|---|---|
| | Rank | 1 | 2 | 3 | 4 | 5 |
| Create Synergy | | | | | | |
| Shared Learning | | | | | | |
| Reduced time to ramp to volume | | | | | | |
| Produce identical chips | | | | | | |
| Produce same ISO/Quality levels | | | | | | |
| Reduce risks in process transfer | | | | | | |
| other: | | | | | | |
| other: | | | | | | |

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Copy EXACTLY! Project questionaire

Rank in order of importance the issues under your authority/control under the Copy EXACTLY! program.( 1 = most important, there can be no ties) Also indicate the importance of the issue to process stability.

| | Rank | very unimportant | somewhat unimportant | neutral | somewhat important | very important |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| Preventative Maintenance Procedures | | | | | | |
| Operating Procedures | | | | | | |
| Installation methods | | | | | | |
| Physical layout | | | | | | |
| Reciepe | | | | | | |
| Specifications | | | | | | |
| Equipment Layout | | | | | | |
| Process Improvements | | | | | | |
| Equipment Improvements | | | | | | |
| Operational Improvements | | | | | | |
| Automation | | | | | | |
| Clean room environment | | | | | | |
| Materials (gases, chemicals, Targets, etc.) | | | | | | |
| Statistical Measures and Procedures ("SPC") | | | | | | |
| Analytical Equipment | | | | | | |
| other: ____________ | | | | | | |
| other: ____________ | | | | | | |

What are the additional tools and/or systems (i.e. A-Team, JET, Communications, etc.) that must be developed in order to make Copy EXACTLY! work as intended?

How is Copy EXACTLY! changing the way in which you work?

What are your professional rewards, if any, for using Copy EXACTLY! ?

What makes a process transferable?

What makes a process sustainable?

Does a transferable process make for a sustainable process? Why or Why not?

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Copy EXACTLY! Project questionaire

For your functional area, rankin order of importance the ten most important process parameters that must be controlled to ensure consistent quality? Do the process tools and analytical support equipment that Intel uses allow these process parameters to be controlled with adequate resolution?

Process Step: ____________________

| Rank | Process Parameter | Resolution Control | |
|---|---|---|---|
| | Length of time a wafer is exposed to the process | Inadequate | Adequate |
| | Thermal cycling of wafer | Inadequate | Adequate |
| | Thermal history of wafer | Inadequate | Adequate |
| | Temperature of process step | Inadequate | Adequate |
| | Environmental temperature | Inadequate | Adequate |
| | Environmental Partical Count | Inadequate | Adequate |
| | Partical Count at Wafer Surface | Inadequate | Adequate |
| | Gas Flow within Reaction Chamber | Inadequate | Adequate |
| | Gas Flow at Wafer Surface | Inadequate | Adequate |
| | pH of processing fluid (specify fluid ____________) | Inadequate | Adequate |
| | other - specify : ______________________________ | Inadequate | Adequate |
| | | Inadequate | Adequate |
| | | Inadequate | Adequate |
| | | Inadequate | Adequate |

For you, what are the behaviors that lead to:

a. promotion
b. salary increases
c. special recognition
d. professional recognition
   i. inside Intel
   ii. outside Intel

For your counterpart in development/manufacturing, what are the behaviors that lead to:

a. promotion
b. salary increases
c. special recognition
d. professional recognition
   i. inside Intel
   ii. outside Intel

Do you feel that the reward and incentive system in place at Intel is conducive to performing well under the Copy EXACTLY! paradigm?

a. If not, Please describe what you feel is not appropriate.
b. If so, Please describe what you feel is working well.

Why use Copy EXACTLY! if there is a clear and measurable benefit in changing a process step or procedure?

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Copy EXACTLY! Project questionaire

Rank in order of importance under Copy EXACTLY! the following performance criteria: ( 1 = most important and 7 = least important, there can be no ties)

_______cost
_______quality
_______dependability
_______flexibility
_______innovativeness
_______time to ramp to volume production
_______meeting performance criteria (Fab indicator targets)

What effect does Copy EXACTLY! have on innovativeness and risk taking?

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