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Abstract

This case on management of innovation in the semiconductor industry studies engineers developing new products at a leading semiconductor company in Japan and one in the United States. How these two companies successfully manage tension between control and creativity is documented and discussed. The management of creativity and control operates differently in Japan compared to the US. A trade-off appears to exist between supporting information sharing for joint knowledge development and supporting individual creativity in developing knowledge.

Introduction

This case study focuses on the management of innovation in the development of a new product and its required processes in the semiconductor industry, where innovation is critical to long-run competitiveness. In particular, we examine how work organization, incentive systems, and communication systems affect the creation, sharing, and control of knowledge. The semiconductor industry is characterized by rapid technological change, high capital costs, continual price declines, and strict quality standards. These industry characteristics result in high risks and returns from product innovation. They also make the semiconductor industry ideally situated for exploring technological innovation.

Long-run competitiveness of a leading-edge company depends on its product line. Over time, a leading-edge company must develop new products that the market values. The challenge for an industry leader is to bring a new product to market and recoup development costs during the short period when competition is limited and prices are relatively high. This case study focuses on innovation by engineers in developing new products. The management of the trade-off between control and creativity, which are inherent in innovative activities, is studied at a leading Japanese producer of memory chips (pseudonym "JapanTech") and a leading American producer of logic chips (pseudonym "USTech"). This research is based upon several field work trips to USTech and JapanTech in the mid-to-late 1990s.

In development activities, two major tensions are studied:

- the tension between encouraging new ideas and the need to choose only a few of the ideas to be used in the new product and process;
- the tension between encouraging individuals to own and develop new ideas and encouraging engineers to share their ideas with a team for more rapid evaluation and development of the idea.

As we will see, the management of creativity and control operates differently in Japan compared to the US. Since large firms in Japan have similar compensation systems, which are largely shaped for the junior engineers through negotiations with the union in national annual wage bargaining and through widespread national employment practices, much of what we observed at JapanTech is representative of other large Japanese electronics companies. In the U.S., few electronics companies have union representation, and employment practices are more widely varied across companies than in Japan. Therefore, USTech's employment system cannot necessarily be thought of as representative of other large U.S. semiconductor companies. In our analysis of USTech, we will indicate which practices are widespread and which seem to be idiosyncratic in the industry.

JapanTech's HR system relies on teamwork and group responsibility with engineers engaging in a broad range of job tasks. Engineers' education is developed through company-based classes, mentoring, and job rotation. Compensation reflects specific career ladders rather than company or individual performance. Engineers participate in knowledge sharing through presentations at conferences and patent applications.

In contrast, USTech's engineers specialize in either development (advanced degrees) or fabrication activities (BS degree). The development engineers are given individual autonomy and responsibility with large monetary rewards for good performance. USTech's policy is not to share knowledge with the outside world; engineers rarely write or present papers or submit patents (except defensively). USTech's practices reflect educational requirements for development engineers and the leading edge nature of the technology under development. Compared to USTech, other U.S. semiconductor companies have less strict policies of knowledge sharing, since they usually believe they have something to learn in the process. Although other companies usually do not give as much responsibility to new graduates as USTech, giving engineers individual autonomy and performance rewards are widespread practices in the U.S.

Organization of development activities both accommodates and requires these differences in the U.S. and Japanese HR systems, and simultaneously they determine innovation, diffusion, and control of knowledge. Precisely those structures of the Japanese firm that support team-based learning and problem-solving impose constraints on individual initiative and autonomy. Precisely those structures of the U.S. firm that support individual creativity and breakthroughs impose problems of control over the process.

A trade-off appears to exist between supporting information sharing for joint knowledge creation and supporting individual creativity in knowledge development. The Japanese human resource system has highly developed systems to support interfirm knowledge creation and sharing (i.e., the joint development of ideas with or acquired knowledge from other firms) and intrafirm knowledge creation and sharing (i.e., the joint sharing of knowledge and skills among employees within a team and across groups). The U.S. human resource system is better at structuring and rewarding individual, as opposed to group, initiative and endeavors. Although U.S. companies do not have a history of interfirm knowledge sharing, U.S. semiconductor companies recently have been experimenting with joint ventures with other companies, largely in response to extremely high capital and research and development costs. In addition, U.S. semiconductor companies have increasingly turned to young companies (start-ups) as an important source of innovation, and often acquire the company or license the technology instead of developing the technology internally.

The Development Process

The development team has to simultaneously fulfill several management goals, including the development of a new product that satisfies customers and is designed for low-cost, high-quality manufacturing. Often management will use specific rules to help guide the development process, such as a ceiling on the number of new fabrication steps and new types of equipment (or conversely, the process must use certain equipment). These types of specific rules governing constraints on process steps or equipment are much easier to identify and implement (as well as negotiate) than management of the creative process itself. Here we will focus on the tension between encouraging individual autonomy and creativity and controlling the direction of the development process, including the use of teamwork for encouraging, evaluating, and controlling individual ideas in the development process.

Issues of creativity and control arise throughout the development process. We will examine how the following relevant decisions are made at USTech and JapanTech:

- how well-defined the characteristics of the process are and how well-defined the constraints are (e.g., equipment that can be used) in the assignment made to the development team;
- how the "winning" technologies are chosen and assigned to team members;
- how the ideas generated by the team members are trimmed down to a manageable number and the members rewarded for their contributions;
- how work assignments are made over time as development proceeds, and how much autonomy the members and the team have in making decisions;
- what sources the engineers use for generating and developing ideas, such as referring back to previous processes, reading theoretical literature, brainstorming in team meetings;
- what sources the engineers use for information and feedback, including scientists at the central research labs, team members, engineers at the receiving fab, marketing experts or customers, engineers at other companies, or publicly-available technical information.

The development process at USTech.

At USTech a strategic planning committee defines new lead products by marketing segment. A strategic capabilities committee ensures that capabilities cut across business segments and lays out process capability over time, which defines the technology roadmap. The goals of the development team are set by a strategic planning committee, which annually updates the technology roadmap and the lead product for each new technology. Since any process change involves a lot of time and resources, a process change must be big enough to make a significant difference in the products manufactured. The planning committee makes the selection of architecture and gives only one option with design rules to the development team. The design of circuit and block architecture with layout is done at the research lab.

Since the new technology is not compatible with the available process, the development team's goal is to build a prototype of the product that is commercially feasible. In order to differentiate between problems caused by modifications of the process versus the product, a new design is brought up on the old process in small volume, and then the first shrink in line width (e.g., from .25 microns to .18 microns) is usually made on the new process. This minimizes debugging problems since it decouples the new design from new technology (process). The development manager issues design rules based on algorithms (e.g., 70% of former size), and the design of the first shrink of the product is done in the development fab. Next, the product is brought up on a new process at high volume. The development rules issued provide very simple "rules of thumb"; for example, 30% of the steps are new (70% are old), and the equipment associated with any given module lasts two generations (i.e., through two different instruction sets or recipes). Learning across development teams is facilitated by keeping archival records of project decisions throughout a program, and performing a "postmortem" after a project is completed to see what can be done better next time.

This structure of development activities reflects the company's strategy of remaining the product market leader. Time to market is an important consideration and short-run financial considerations are not dominant, so much of the work traditionally done at the manufacturing fab, including the ramping to volume production, is done at the development fab at USTech. The transfer rule is to freeze the technology and transfer it to the manufacturing fab when the development fab has no fundamental yield or manufacturing problems at a volume of 2000 wafers per week. If the development fab can produce 2000 wafers per week rather than the more traditional 300 wafers, then volume-related problems will have already been solved and fab engineers become "believers" in the process. By ramping to volume at the development fab, the development engineer is forced to learn and use manufacturing skills. This encourages "developing for manufacturing" (i.e., developing in a way that minimizes manufacturing problems and costs) since the development engineer experiences the problems at high volume and does volume-related problem solving.

In order for the manufacturing engineers to have ownership of the new process and to make use of their manufacturing skills, they are transferred to the development fab up to eighteen months before the transfer. Their role is to set manufacturing goals, define optimized recipes, set up maintenance procedures, transfer deliverables (documentation, knowledge), undergo training, and help characterize the process. Although they help in the qualification of the product and the transfer process, their primary tasks are to be trained to run the new process and to manufacture the chips at the development fab.

The management style at USTech is distinguished by the cultivation of peer pressure, aggressive discussion of ideas, delegation of responsibility to young engineers, and job assignment along with stock options as rewards. In general, job assignment reflects the degree of complexity of the task and the experience and knowledge of the person. A junior engineer is assigned an open-ended but less complex problem. A senior engineer has a more detailed assignment with a complex problem. USTech believes that lack of experience is beneficial in research and development, since an inexperienced engineer does not have preconceived notions of what works or doesn't work. For this reason, young engineers are given major responsibilities in developing new processes or technologies. Managers described new graduates as providing a role model for older workers, since they are hard working and creative in their problem solving.

Assignment of the correct people to a project is critical. Engineers are rewarded for excellent performance by their next job assignment, and this provides a major incentive to do well. Job assignments determine compensation, which is strongly performance based. Those who do not do well are assigned tasks with a lower level of responsibility. Only in rare instances do engineers ask for more challenging work or projects, and, in response, they are told they need to perform well on simple tasks first. Engineers reported enormous peer pressure; "sitting back is not condoned." Some engineers, who cannot make the required breakthroughs, burn out and quit. However, USTech restructures assignments when projects are not going well. One example was given of a key engineer who "blew it" on a huge project, so the project was split into two parts, core and support, and he did support.

Conflicts about ideas are resolved through confrontation, or a process of "disagree and commit". If a technology being developed is dropped or not integrated, younger module engineers may be discouraged. However, in a conflict about which idea to use, the boss may ask the dissident to run the project. Engineers typically do not withhold their ideas in the development process, which is problem driven. This is more of a problem in research, which is idea driven.

USTech relies on decision-making through committees, and one's influence in the company is determined by how many standing committees one is on. Everyone is part of a group, and engineers have a bi-weekly one-on-one meeting with their group leader at which they can bring up problems. USTech is typical of U.S. semiconductor companies in its reliance on teams making the decisions that structure work. The team decisions are supplemented by individual decisions and have limited managerial input, once deadlines and schedules are set.

USTech has a formal methodology for learning new knowledge:

1. Search the literature. Engineers think that papers from universities are better than company papers. However, Sematech has increased the quality and number of industry papers.

2. Compare methods used across equipment sets (e.g., read a report on defect mechanisms on thin film and see if it works on etch).

However, USTech engineers reported that the technical literature is not very helpful "because if anyone is doing (a solution to the problem under consideration), they are not sharing it; if they are sharing it, they are doing it poorly." The engineers often find industry papers misleading, since a paper may show only the best picture and not report other cases. The partial reporting is hard to evaluate, and the process usually doesn't work as well as reported. Normally, USTech engineers do not publish anything outside the company, since publishing is not important for career advancement within the company or for professional reputation. USTech engineers are very proud to be working for a technology leader, and they share in the cachet of the company's name.

The engineers at USTech are very clear that any information sharing with outsiders has to be done on a quid pro quo basis. Employees are aware of the risk of information transfer because they have taken classes on internal document control and are familiar with past cases where intellectual property was transferred illegally. Even within USTech, engineers need to have a reason to request company papers. In general, they do not rely upon the exchange of knowledge with outsiders because "outsiders have nothing to share." The company policy is not to answer questions from outsiders, since USTech receives nothing in return. However, some engineers indicated that customers and colleagues at other semiconductor and equipment companies are important sources of technical information.

Control over ideas is further ensured by using the patent process defensively. There has been a renewed emphasis on patenting at USTech, especially in the process architecture area. Engineers are paid $2000 for filing a patent. The rule of thumb is to keep knowledge a trade secret, but to patent whatever can be reverse engineered. For this reason, process integration does not need to patented.

USTech is typical of U.S. semiconductor companies in its engineers relying on company colleagues and on journals and not relying on patents for technical information. Engineers at other U.S. semiconductor companies are much more likely to share with outsiders through conferences or personal contacts. USTech engineers seem to feel rewarded for their creative achievements through their national reputation of working for USTech without presenting papers at conferences.

USTech pays their engineers based on individual performance. Usefulness of ideas is the main factor in the annual performance review, which includes a qualitative summary of accomplishments and the employee's strengths and weaknesses. Performance is evaluated on a relative basis by ranking engineers on an equity curve by quartiles. An engineer is ranked within a group of 10 to 20 engineers in his or her own grade range. They are told their relative ranking (e.g., top one-third) and given a rating of superior/outstanding (15%), successful (80%), or needs improvement (0-5%). Each person is also told if their performance trend is greater or less than their peers. The evaluation can affect pay within the rank group up to 10% (e.g., those with superior receiving a 6% pay increase, with good receiving 4%, etc.) plus promotions and responsibility on the next job. Everyone is considered well paid, and they do not know each others' rankings.

Compensation can include profit-sharing and stock options as well as salary. Exempt and nonexempt employees have the same cash bonus system, which is based on six month company profits (e.g., 5 to 7 days of pay). Higher grade levels (i.e., beginning with the grade level at which PhDs enter) receive an executive bonus (percent of base pay), which varies by position and payoff rate. Stock options are paid for future potential and are an important incentive mechanism. Some engineers earn more from their stock options than from their salary. All grades are eligible for stock options but with different participation percentages. For engineers, the bottom 10-15% do not receive stock options; the middle 70-75% receive some options; the top 15% are identified as key players and receive more options.

Promotion is also used to reward outstanding performance at USTech, which develops its engineers, and many rise within the company. Engineers can be promoted to group leader, whose job is still highly technical with supervision of approximately six engineers and a few techs. The group leader must have been at USTech at least four years. Competition for group leader is keen, and those passed over are miffed and ask "Why him and not me?" The group leader reports to an area manager, who has been at USTech for 10 to 19 years and supervises 50 to 150 people. The area manager is the big step into management, since the job is less technical and requires more leadership and administration. Senior engineers who do not go into management have a parallel path and report directly to an area manager. Less than 20% of engineers are on this track. So far, USTech's growth rate has allowed a satisfactory rate of promotion, but this might become more difficult to achieve as the company matures.

The development process at JapanTech.

At JapanTech, development of the business plan, which includes discussions from users on what will sell as well as production requirements, is an important process. The plan for memory is sent to the R&D division annually. The development process is conducted for two years by the central research lab, which undertakes research for all the divisions of the company (including semiconductor) and then by the development team for two years before it is handed off to the memory division. Central lab engineers produce fundamental research reports and then develop process architecture and modules (i.e., circuit design) based upon this research. Until last year, they also developed the engineering sample.

At JapanTech, the development process is divided into three stages: research, development, and fabrication of the engineering sample. The development lab does the prototype development, which includes development of the new technologies and integration (i.e., the process for fabrications) as well as actual fabrication of a prototype. A cooperative relationship exists between the central research lab and the development lab. Since the semiconductor division commissions research on future technology, it is in charge of the research plan, and funds and receives the research results. The development lab also develops the engineering sample (i.e., establishes the process, confirms characteristics, and completes and ships engineering samples to the engineering division). The engineering sample is then handed off to the business division, which makes the commercial sample and then transfers it to the fab. The hand off to the fab is made at an early stage (e.g., 5 good chips per wafer). In a recent transfer, they needed over 1000 wafers to establish reliability. The biggest challenge is transferring technical know-how to the fab and understanding where equipment bottlenecks will occur in volume production. The number and complexity of the modifications that are made decrease as the development progresses (e.g., in a recent generation, five to ten mask changes were made in the engineering sample, fewer than five changes were made in the commercial sample, and three to four minor mask changes were made at the first receiving fab.)

Daily technical reports during development of the prototype device total 2000 pages per device; there are far fewer reports during the engineering sample stage. In contrast, meetings for prompt exchange of information between engineers become more important the further they are into production. Process engineers communicate with production engineers weekly in the early stage and then daily in the last stage. JapanTech estimates that each stage costs approximately the same amount. Since development resources are limited, the strategic decision of what device to concentrate on is important. JapanTech is continually adjusting resources to research, development, and production.

Participation with equipment vendors appears controlled and contingent on the characteristics of the equipment under consideration. When the product requires specialized nonstandard inputs from the supplier, or when the equipment is being tailored to the specific needs of JapanTech, participation with the equipment vendor is extensive. When these conditions are absent, there is relatively little participation. Once purchased, equipment performance is continuously monitored. Since equipment is not restricted to specific devices (i.e., semiconductors), one of the first decisions made is what equipment on hand would work for the device (i.e., product) being developed and what equipment needs to be purchased. For the existing equipment chosen for continued use, production engineers make the equipment modifications for the new device. These modification projects give the equipment engineers the opportunity to work on a creative project.

JapanTech engineers have discussions with equipment manufacturers on how to reduce price, on what machine options to order, and on required safety requirements for machines, which differ by prefecture. Today they are more frank in discussions with equipment vendors than previously, since the "cost of hiding information is perceived to be too high". JapanTech's openness with the equipment vendors (in contrast to USTech) reflects the widespread use of similar equipment throughout the memory sector and the decline in the price of equipment as modifications become standardized.

JapanTech has introduced a "total concept" approach to improve communications between engineers; design, process, and product engineers must work together to produce total concept through meetings and rotation. Discussions with equipment and materials manufacturers are also integrated into this process. The goal is to focus on innovation in product design, since the days of price competition and incremental improvements have been replaced by emphasis on innovative products. The "total concept" approach includes six months of education on the production line for junior development engineers before they specialize in engineering tasks. Half of new hires at the development lab have spent six months on the production line, and one-fifth of all development engineers have spent six months on the line.

The project leader assigns work and makes schedules according to abilities. Ideas are generated about technologies by team members. When a new idea is created by an individual, verification and evaluation of the idea is performed through fabrication by the test team, which decides the best choice for the new technology. In the final stage, however, there is no time to try ideas by making samples, so the leader chooses among competing ideas. The person whose idea is rejected is usually discouraged for a short time. The project leader tries to pick an idea as soon as possible and rejects other ideas right away, even if they are equally good. He will consider using the rejected idea in the next generation. Usually only small problems have many ideas for a solution; conflicts among important ideas do not occur frequently.

In the development of the device we studied, only two major technologies were changed. To develop the two technologies, a team was appointed that consisted of the leader (shunin) with five engineers for process development and three engineers for circuit design. The shunin learns about basic information from central lab members and about customer information from the memory division. The shunin's supervisor (kacho) decides the main job targets for the shunin, who decides job assignments for members. The shunin also does a lot of training for the members.

Compared to the U.S., Japanese managers appear to be more involved in assigning tasks and less involved in setting deadlines. Compared to the U.S., teams appear to be more involved, and individuals less involved, in prioritizing tasks in Japan, and individuals are more involved in setting deadlines in Japan.

On-the-job development of skill level for engineers is intended to include development of originality and creativity. Job rotation is a major mechanism for skill development. The goal is to rotate the jobs of the group members yearly across devices and stage (e.g., year 1 in research on two generations out; year 2 in development of the next generation; year 3 in fabrication of the engineering sample with 80% of time on the fab line of current generation device). For example, one group had 10-14 team members in development, 2-3 members (with none next year) in fabrication, and 4-5 members (growing to 5-7 next year) in research.

Japanese engineers would rather do research and development work than fabrication work, which is hard and hands on ("for an operator and not suitable for self"), and the breakthroughs and patents are mostly in research and development. However, the company believes that fabrication work has important educational aspects so engineers are required to work on fabrication.

JapanTech also uses the transfer of engineers to transfer knowledge. This is part of their policy of periodic job rotation between R&D, the business division, and the fabs. At the time of transfer, development engineers are sent to the manufacturing fab for one month. However, one to two engineers (process and design) are sent for two years from the production fab to the business unit fabricating the commercial sample. A number of engineers are sent to the volume fab for the hand-off. In the latest generation, the hand-off to the second high-volume fab six months later needed only one-tenth as many engineers as the original fab.

For JapanTech's development engineers, an important goal is to be one of the first companies to present a paper on the next generation memory device, which marks its public debut at the ISSCC international conference. The companies already know about individual processes before the presentations at the ISSCC conference, where they learn what the other companies are emphasizing and their general direction of development. However, companies do not present information about process integration at the ISSCC conference. Overall, the ISSCC is important for motivating engineers as well as for marketing and sales.

Like other large Japanese companies, a complex system is used to determine monthly salary, which is a combination of age pay plus grade and position pay. Until they reach management, which typically takes twelve or so years, engineers are in the company union. During this period, earnings are fairly rigidly set with only minor variations among engineers with the same education and tenure. Monthly salary and bonuses are negotiated with the union, and annual increases are determined by national wage negotiations in the spring (Shunto, or annual spring offensive.) Twice yearly, employees are paid a bonus (annual average of 5 months), with performance accounting for up to 25% of the bonus. Performance pay amounts to only a small fraction of regular salary, with recognition being more important than money. However, performance affects one's rate of promotion, especially to management, which begins with the position of kacho. All group leaders now become a kacho. However, with the aging of the work force, JapanTech is running into the problem of too many shunin, so more engineers must become technical specialists (tanto kacho). Currently, JapanTech is experimenting at the development lab with paying an annual salary based more on performance and less on experience and grade.

At JapanTech, an annual goal is 3 to 4 patents per engineer. About Y5000 is paid at the time of patent application and about Y10,000 is paid if accepted (license). In the infrequent case of a patent being used in the product line, a much bigger reward is paid (Y1,000,000). Patents in the development lab are mostly for process (80%, of which 70% is process only and 30% is equipment only) with the remaining 20% for circuit design. All equipment patents are connected to process development.

Like other large Japanese companies, JapanTech relies on company-based education for the development of its young engineers, who are hired after receiving a BS. Unlike their American counterparts in R&D, Japanese engineers usually do not have masters or doctoral degrees when they go to work for a company. They will often receive an advanced degree from their company or from an affiliation with a university while working for a company. JapanTech's development lab has only 2 PhDs, one from a university and one from the company.

Conclusion

JapanTech and USTech use different employment systems to manage their product development. Both companies have HR systems made up of consistent and re-enforcing parts, which reflect both their product and labor market environments. As a producer of logic devices, USTech's goal is to control the market for their devices by maintaining a lead over potential competitors in introducing the next generation. Time to market, but not price competition, is an important part of strategy. As a producer of memory, JapanTech's goal is to keep up with their competitors in introducing the next generation. Since generations are now separated by only two years, the time to market and price competition are both important parts of their strategy. JapanTech's labor market institutions include lifetime employment, annual national wage determination, a company union, and a higher education system that does not provide much research or graduate education. USTech's labor market institutions include decentralized and individualized wage setting in a mostly nonunionized industry, a mobile labor force, employees accustomed to a high degree of autonomy and input into the job assignment process, and a higher education system known for its research and graduate education. Here we compare the major differences in the resulting HR systems:

Work organization:

- Job assignment reflects past performance and expected future performance at USTech, while job assignment at JapanTech reflects project's requirement for skills and knowledge already acquired, and the plan to develop the knowledge of junior engineers. USTech rewards development engineers for outstanding performance by assigning them more responsibility on their next project. JapanTech assigns development engineers to projects on the basis of company needs and requires more rotation among different types of tasks, including fabrication.
- Although engineers at both companies prefer to do the more challenging development work rather than the mundane tasks such as documenting modifications and calibrating equipment, this problem seems to be more widespread at JapanTech since most engineers do not specialize in development or manufacturing, and they begin work with a BS degree. At JapanTech, engineers (excluding the Central Research Labs) rotate among development and fabrication tasks. USTech's engineers are more specialized, and their work reflects their education with development and research engineers likely to have advanced degrees.
- A confrontational style is practiced at USTech, but disagreements are put aside after a commitment to an idea is made. Autonomy and creativity are highly prized at USTech in development (but not in manufacturing). A consensus approach is practiced at JapanTech, and teamwork and stability are highly prized.

Incentive or compensation systems:

- Both companies use a relative performance ranking system to evaluate their engineers, but the rewards for performance are different. Pay, especially for the first dozen or so years while the engineer is in the company union, is more rigidly set at JapanTech than USTech, which is more performance oriented. USTech focuses on rewarding an individual's ideas and efforts. Although both companies pay bonuses, the bonus at JapanTech mainly reflects national wage setting while the bonus at USTech reflects performance at the unit, division, and company levels. Also, USTech engineers can be richly rewarded with stock options.
- JapanTech is struggling with the aging of its work force and the declining demand for managers relative to those eligible. In a two-tier management system, JapanTech is exploring how to provide cost-effective incentives to older professionals who are specialists and do not supervisor employees. A younger and faster growing company, USTech only mentioned this as a potential problem. However, USTech's performance-oriented and flexible compensation system allows it to deal with changing company needs and employee demographics more easily than JapanTech's

compensation system, which is more dependent on rigid job grades and career ladders.

Knowledge development and communication systems:

- USTech engineers rarely make public presentations, publish papers, or share information with outsiders (including vendors), since USTech believes there is nothing to learn from others through sharing knowledge. Patent applications are made only if the knowledge can be learned through reverse engineering. In contrast, JapanTech depends on public presentations to maintain its reputation and to announce the introduction of new devices. Knowledge sharing with suppliers is part of the equipment development process. Engineers are expected to submit 3-4 patents annually. The publication of papers, patent applications, and conference presentations are important for keeping up with the competition and for the advancement of an engineer's career.

- When research engineers with advanced degrees are hired, often straight out of the university, to work for USTech, they are assumed to have the research skills necessary to undertake their own research projects or the manufacturing skills necessary to oversee the operation of specific equipment. Both research and manufacturing engineers go to work for JapanTech after graduating with a BS degree. They are expected to learn on the job through their team work, continual firm-based training, and job rotation that usually includes both development and fabrication activities. Some engineers earn advanced degrees while working, either from the company or from an affiliated university.

- At USTech, junior development engineers are given major responsibility for developing new technologies. At JapanTech, major assignments are given to subteams within a team setting, and new ideas are evaluated by a test group. Junior engineers are assigned to work with senior engineers and are expected to learn through their work assignments.

A company's strategy for innovation in development is intertwined and reflects the relative importance in maintaining market control (i.e., remaining first to market for a particular product) versus the relative importance of keeping up with the competition in delivering new products at competitive prices. USTech is an example of the former situation and JapanTech is an example of the latter. USTech encourages new ideas by having their development engineers highly specialized and by assigning major responsibilities for solving a specific problem to one or two engineers. USTech controls the development process by requiring design specifications. Engineers who are successful are highly rewarded both monetarily and by their next assignment; those who are not successful are likely to leave.

JapanTech's transfer of new technology occurs early in the process after only a few good dice (chips) are produced in the development fab. The group leader decides at an early stage among competing ideas, primarily based on the results from the test team. The junior engineers' education continues within the company through working with senior engineers on projects and through formal classes. JapanTech also believes that job rotations that include fabrication as well as development assignments are an important part of the education process. Since an engineer's career depends on the team's presentations at conferences and patent applications, individual creativity is less important than team outcomes, and the individual is granted less autonomy and responsibility by the group leader.

Overall a system emphasizing individual autonomy, responsibility, and reward for development engineers, along with no knowledge sharing with outsiders, characterizes USTech. A system of team work, explicit career ladders, and company-based education for engineers, who do not specialize in either development or fabrication jobs, along with required sharing of knowledge through required patent applications and presentation of papers, characterizes JapanTech. Consistent with the external environments imposed by their product and labor markets, these approaches resulted in USTech being a top performer in logic and JapanTech being a top performer in memory in the 1990s.

Since the research for this case was completed in the late 1990s, the marketplace for USTech and JapanTech has changed considerably as the markets for consumer electronics, telecommunications, and computing have been converging. Semiconductors for PCs and simple cell phones have become a smaller share of the industry, and the rise of a variety of networked mobile and audio-visual products has made identifying winners a difficult and risky undertaking. As a result of the changing marketplace, USTech and JapanTech are in the process of changing the employment systems documented above. USTech has become more open to sharing knowledge through presentations and reports, and the company is more actively engaged in the high-tech community. Creative activities now span a larger knowledge set, and control over engineers' activities has been relaxed somewhat. The turnover rate at USTech is lower than at other large US semiconductor companies. If the turnover rate should rise, then USTech will become concerned with how to control their engineer's knowledge sharing with the outside world. As JapanTech has struggled to become more innovation in their product line, JapanTech has been working to increase individual incentives for creative performance and to give young engineers more autonomy in their job assignments. However this must be done with union approval, which has slowed down the process of change. Although JapanTech has made progress in supporting and rewarding individual creativity, team work is still its forte in pursuing innovative development. Time will tell if JapanTech is able to recapture market share, and if USTech is able to maintain a leadership position in the emerging marketplace.