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**MATCHING JAPAN IN QUALITY:
HOW THE LEADING U.S. SEMICONDUCTOR FIRMS
CAUGHT UP WITH THE BEST IN JAPAN**

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MITJP 93-01

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Summary of Article

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In the early-1980s, it was clear to a number of U.S. companies that Japanese semiconductor firms had a focus on quality assurance that was driven by a set of management practices that were neither as widely evident nor as intensively practiced in the United States. The set of Japanese practices that led to their ability to outperform U.S. companies included a focus on a manufacturing as the locus of quality, defining quality objectives in terms of manufacturing goals, and using a "total quality" approach to quality assurance. U.S. semiconductor firms, faced with a severe quality gap in the early 1980s, pursued a strategy of wholesale copying of the Japanese total quality philosophy. By careful adaptation of successful Japanese quality assurance practices to better fit with traditional Western management culture, and with the help of organizational innovations like SEMATECH, some U.S. semiconductor firms were successful in catching up with their Japanese competitors. The objective lessons from the strategy used by the U.S. semiconductor firms are important for other U.S. industries facing similar competitive challenges to understand.

MATCHING JAPAN IN QUALITY: HOW THE LEADING U.S. SEMICONDUCTOR FIRMS CAUGHT UP WITH THE BEST IN JAPAN

Dr. William F. Finan[1]

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Introduction

U.S. industry has been under great pressure to respond to intensifying global competition, especially from Japan. Almost no industry has faced more intense Japanese competition than the U.S. semiconductor industry. Beginning in the late 1970s, Japanese firms steadily gained market share. But, unlike other industries facing Japanese competition, in the past two years, the U.S. semiconductor industry was able to arrest and then reverse this trend. By 1992 the global market share of the Integrated Circuit (IC) market held by U.S. firms nearly equaled that of Japanese firms: 41 percent versus 43 percent.[2]

While there are many aspects of U.S.-Japan competition that factor into the story behind the recovery of the U.S. semiconductor industry, one important one that has received almost no mention is the role of improved U.S. quality. Over the past twenty five or so years, Japanese firms had demonstrated a consistent ability to achieve superior levels of quality relative to American firms. But a number of American semiconductor firms in the mid to late-1980s aggressively responded to the quality-led strategic thrust of Japanese producers and significantly narrowed the Japanese quality advantage. Closing the quality gap in the 1980s was undoubtedly one critical element leading to the recovery of the U.S. semiconductor industry's global competitive position.

In order to judge the degree of U.S. quality improvement in the 1980s, compare the rate of defective parts shipped for U.S. and Japanese memory producers.[3] In 1980, Japanese producers of leading edge semiconductor memory devices, a bellwether device family, were achieving an average rate of 160 defective *Parts Per Million* (PPM).[4] At the same time for the same devices, American producers had an average rate of 780 PPM, or nearly five times the Japanese average.[5] By the late 1980s, Japanese memory producers had reduced their defect rate to around 100 PPM. American firms had also reduced their defect rate to the same level.[6] How did U.S. firms accomplish this feat in such a short period of time?

The success of American firms such as Texas Instruments (TI), Motorola, Intel and others, lay in their wholesale adoption of many of the principles of quality assurance employed by their Japanese competitors. But, while they adopted Japanese principles, the American companies modified the Japanese practices used to implement them. This permitted the U.S. firms to more readily weave the Japanese principles into the management fabric of a Western firm.

Quality in the Context of Japanese Semiconductor Firms' Strategy

From about the mid-1970s, Japanese semiconductor firms saw superior quality as the strategic competitive tool to forge their way into important segments of the U.S. semiconductor market. Efforts to penetrate the U.S. market were focused on leading edge U.S. customers, such as IBM and Hewlett Packard (H-P), where quality weighed heavily in the purchase decision.[7] By the early-1980s, it had become clear to a number of these leading edge customers that the Japanese semiconductor firms had a focus on quality assurance that was driven by a philosophy and a set of management practices that were neither as widely evident nor as intensively practiced in the U.S. semiconductor industry.

There were both internal and external management components to the Japanese approach. Both were important to sustaining their ability to achieve higher quality levels than their U.S. rivals.

Internal Management Philosophy And Practices

The internal Japanese philosophy towards achieving high levels of quality had three notable characteristics. None of these characteristics were evident in the U.S. industry in the late 1970s, early 1980s period. First, the quality assurance strategy was developed around manufacturing capabilities. For example, an article written in 1982 by a manager of Matsushita's semiconductor operations stated: "It is said that 'inspection does not improve quality. Good quality is produced in the manufacturing process.'"[8] Defining quality in terms of the effectiveness of their manufacturing operations meant that, for Japanese managers, quality was more than simply something achieved on the surface of the company; it was embedded into the very core of the Japanese firm. This philosophy contrasted sharply with the then dominant U.S. philosophy of investing heavily in final test to sustain outgoing quality levels.

Second, the focus on manufacturing operations led Japanese managers to define quality assurance goals in terms of manufacturing-related objectives. To illustrate, take the statement of a plant manager at NEC semiconductor's Yamagata operation: "[Quality] means improving manufacturing yield and reliability...In order to improve the quality of products and operate the production system efficiently, zero breakdowns and zero defects must be the goal."[9] This was a very typical view throughout the Japanese industry.

Third, Japanese managers took a comprehensive view of the factors that influenced quality in their manufacturing operations. Quality involved every aspect of the organization from management decision-making down to, and including, training of line operators. A report on improving quality prepared by the management of Fujitsu's semiconductor operations expresses this view:

> The approach for 'zero defect' and 'securing yield absolutely' begins with thorough facility management...In order to use facilities in stable condition, enforcement of cleaning of facilities, inspection, strengthening of maintenance staff in new phases is needed, which is producing good results. Needless to say, united activities of development, facility and production sections are the premise for 'zero defects'...[10]

These differences in the approach of Japanese semiconductor manufacturers towards quality assurance -- a focus on improvements in manufacturing productivity, stating quality objectives in terms of manufacturing objectives, and adoption of a broad definition for quality -- came together in the twin concepts of "Total Quality Control" (TQC) and "Total Preventive Maintenance" (TPM). These concepts originated in the U.S. and surfaced in the 1970s in Japan. They began to be fully implemented in the early 1980s across a number of Japanese semiconductor firms. An NEC presentation discusses the evolution of these concepts in Japan:

> Preventive maintenance started in America. Before 1950, when breakdown maintenance was common, repair work was done only after equipment failed to function. The concept of performing Preventive Maintenance (PM) before such breakdowns occurred took hold after 1950, and got a new twist in Corrective Maintenance (CM), which sought to correct problems before they caused a breakdown. Later, Productive Maintenance came into being, and was performed to maintain high productivity. In the 1960s, Maintenance Prevention, applied during the planning stages, was introduced, in which considerations for reliability, maintainability, and cost efficiency were built into the design.
>
> In the 1970s, we entered the TPM age. This concept incorporated American Productive Maintenance methods into one suitable for Japanese corporate culture. The result is one that respects human value and utilizes everyone's participation for total efficiency...
>
> The number of corporations which develop TPM as a part of TQC has been increasing. Both TQC and TPM execute maintenance and improvement of quality, and have the same purpose of aiming at 'improvement of atmosphere of corporations,' but TPM's mission to advocate the idea of TQC, whose supremacy lies in quality, is more concrete and creates an atmosphere which produces quality on the production floor.[11]

Underpinning these broad approaches to quality management were explicit management practices. For instance, by the mid-1970s, the major Japanese semiconductor firms were applying Statistical Process Control (SPC) methods -- techniques pioneered at AT&T in the 1950s -- to control individual process steps in fabrication and assembly operations in order to reduce variance and defects during production. Again the focus was manufacturing. As Kaneyuki Kurokawa, currently a managing director at Fujitsu semiconductor, explained, "In Japan, the manufacturing group was the strongest member of any company, as evidenced by the success of statistical process control in manufacturing."[12]

Management disciplines needed to effectively apply SPC techniques were already well-embedded in Japanese management culture. These included, for example, process engineers working to incrementally refine process steps in a disciplined, systematic way; rigorous correlation through customer feedback of the occurrence of defects to specific process steps; and training programs for operators to increase their understanding of technical issues in fabrication and testing. In other words, in the early 1980s, aspects of quality assurance that American firms were just beginning to understand were already well-practiced disciplines in Japanese firms.

Three illustrations, line operator training, design of line automation, and equipment reliability, demonstrate how the twin concepts of TQM and TPM were implemented.

Training of Line Operators In the early 1980s, Japanese managers, generally, exhibited a higher degree of confidence in their line equipment operators than did their U.S. counterparts.[13] In Japanese-managed front-ends, equipment operators were expected to perform a number of tasks that, in the U.S., were left to engineering technicians who were more senior and more highly educated. For example, in the Japanese system, the responsibilities for making equipment assists and maintaining equipment operating parameters are under the jurisdiction of equipment operators. In the U.S., such responsiblities were usually left to the more senior technicians. In order for line operators in the Japanese firms to achieve this level of proficiency, a well-trained, well-disciplined operator workforce was essential. One focal point for implementation of TPM was at the operator level, manifesting itself through a substantial and continuing investment in ongoing operator training. As an NEC presentation on TPM stated, "The greatest effect of TPM was in the improvement of human factors...educating staff is most important."[14]

Automation of Production Lines Total Preventive Maintenance concepts influenced how Japanese firms defined objectives for automating their production lines. Certainly, in the early 1980s, strong differences existed between American and Japanese managers' views regarding the ultimate goals of automation. American managers saw automation principally as a means to achieve cost improvements.[15] But this was not an explicit goal of Japanese managers. Their general thrust differed from the U.S. approach in that they set engineering goals and expected the improvement in operating conditions to indirectly result in lower unit costs. Japanese firms automated their front-ends for reasons of quality assurance, for improved processing control, better handling of materials, and more rapid data processing and feedback. All were essential components of TQM.

Improvements in Equipment Reliability Japanese semiconductor managers perceived a close relationship among TPM, improvements in quality assurance, and requirements for greater equipment reliability. An NEC report, for instance, discussing this issue noted:

> [W]e have to have a countermeasure regarding the elements which control yield, especially for the problems surrounding the equipment....The concept of TPM means activities to decrease problems, losses due to deterioration, and maintenance costs. This is achieved by fully checking reliability [of equipment], ease of maintenance, economics and safety based on maintenance information gathered through

independent maintenance, individual improvement, and so forth of existing equipments....We need to determine objective values for each item of equipment for each facility and plan in such a way that those values are achieved during the design stage.[16]

In some sense, the push into TQM and TPM simply formalized management practices already deeply ingrained in Japanese firms.

External Relationships

Strong external relationships with key vendors also contributed to the ultimate success of the Japanese semiconductor industry's drive to enhance quality. The nature of these external relationships in Japan between vendor and customer must be understood in the broader context of hierarchial relationships in Japanese business. A vendor is considered to be an essential extension of a manufacturer's capability to sustain and improve quality. In the context of the general Japanese philosophy, American semiconductor managers, in the early to mid-1980s, found two characteristics of the external relationships especially noteworthy. First, on the downstream side of the external relations, there was extensive feedback of quality assurance data from the systems level customers to the Japanese device makers (and aggressive and thorough study of the data by the device makers to resolve problems).[17] Second, on the upstream side, between Japanese device producers and their equipment and material vendors, there existed a high degree of close coupling. That is, there was degree of interaction involving the continuous exchange of people and technical support. The degree of interaction far exceeded that typically found between a U.S. device company and its vendors at that time.[18]

Both the upstream and the downstream relationships enhanced the quality assurance effort of the Japanese device makers.

Feedback Cycle Between Japanese Device Companies And Their Customers Japanese device companies and their customers:

> [E]stablish a feedback cycle treating the suppliers and users as one body rather than have them in confronting positions....Therefore, [systems] manufacturers have the [semiconductor] manufacturers produce perfect products rather than having to eliminate defects when they carry out inspections. Information concerning quality evaluation from user's point of view is fed back to, and is made the best of, by the part manufacturers.[19]

Close Coupling Among Device Producer And Equipment And Material Vendors With respect to equipment vendors, extremely tight coupling meant, for example, that device firms routinely called on their equipment vendors to provide technical support in all phases of manufacturing, including even the most sensitive stages of developing new production processes.[20] Equipment vendors were also expected to be primarily responsible for maintaining equipment uptime even after installation. The nature of the relationship was one of constant measurement of the vendor's performance. But, as one American observer noted, "There is no premium for good performance, but a drop in performance values may lead to punishment by order cancellation if a trend develops."[21] Thus, while there was greater openness and sharing with the vendor, the burden fell on the vendors to sustain their performance levels.

The combined impact of an internal effort focused on enhancing quality performance in high volume manufacturing together with strong external vendor relationships yielded a higher discernible level of quality in Japanese-supplied semiconductor memory parts in the early 1980s. U.S. customers could identify two significant differences between U.S. and Japanese quality levels. The first difference, as noted above, was that Japanese defect rates were four to five times lower than U.S. rates. The second difference was that Japanese suppliers were able to pass U.S. customers' qualification procedures more rapidly than U.S. suppliers, with fewer iterations through the qualification trials resulting from design or process alternations. Shorter qualification time allowed Japanese semiconductor producers to begin to define product standards for leading-edge devices, in turn facilitating more rapid market penetration.

Reflecting these differences, Japanese producers steadily increased their share of the world memory market until they captured over 70 percent by 1988.[22] At the same time, the Japanese world market share for total ICs increased from twenty five percent in the late 1970s to over forty five percent by the mid-1980s.[23] Clearly the Japanese quality-led strategy had been successful.

Evolution of U.S. Semiconductor Managements' Quality Assurance Strategies

The competitive wake-up call for the U.S. semiconductor industry on its quality problems came in a very public way. In 1980, a senior H-P executive addressing a meeting convened in Washington, DC by the Electronics Industries Association of Japan presented data comparing U.S. and Japanese defect rates for semiconductor memories (actually Dynamic Random Access Memories or DRAMs) purchased by H-P. The H-P data demonstrated that, not only were the Japanese memories consistently shipped with lower defect rates, their average defect rates were, in fact, an entire order of magnitude lower. For some in the audience the message was not surprising. It had been increasingly understood for some time throughout the U.S. electronics industry that Japan's semiconductor producers were able to achieve significantly higher and more uniform product quality.

In the wake of the public H-P disclosure, many U.S. firms started to reassess their approach to quality assurance. Even in the early 1980s, most U.S. semiconductor firms were still relying mostly upon inspection and verification methods to insure final product quality. These methods had their origins two decades earlier with U.S. Air Force procurement programs; at that time, the Air Force was the largest procurer of U.S. semiconductors and had a significant influence over the industry's quality assurance practices. While the Air Force's methods were advanced in the early 1960s, by 1980 they ranked as the less sophisticated. (See Table 1 which defines, in ascending order of sophistication, the four major stages of quality assurance.)

While the Air Force was influential in defining the first two stages of quality assurance practices used in the semiconductor industry, it was the Japanese producers who ulimately defined the subsequent stages that became the norms for the 1980s. In contrast to the Stage Two practices applied at most American semiconductor firms at that time, Japanese semiconductor producers were already basing their quality assurance programs around the more advanced concept of prevention -- Stage Three -- or were well into the transition towards Stage Four or "Total Quality Management" (TQM). Given their use of more advanced quality assurance concepts, the fact that they were able to achieve an order of magnitude of better quality was not surprising.

The challenge facing U.S. semiconductor firms in 1981 was to significantly improve their quality levels by moving to a Stage Three philosophy of prevention. By the mid-1980s, a number of U.S. semiconductor firms had made significant strides towards instituting a prevention-based approach to quality assurance with the adoption of SPC techniques. But even with this change, U.S. defect rates continued to remain nearly an order of magnitude greater than the Japanese. There was a two-fold reason why. First, semiconductor technology had evolved towards sub-one micron features, meaning that circuit designs were smaller and devices were far more difficult to manufacture and test. Prevention-based methods alone were not sufficient to address the complex issues of maintaining quality in the sub-one micron era. Second, Japanese firms were applying a more comprehensive, sophisticated quality assurance philosophy.

As U.S. managers became increasingly aware that they were unable to match the higher quality levels achieved by the Japanese, they began to seek answers. Gradually, through various windows on Japanese firms' practices such as joint ventures with Japanese firms or their Japan-based subsidiaries, more and more

U.S. managers came to understand that the Japanese firms were operating under a very different quality assurance philosophy. The obvious answer to the U.S. quality problem lay in adopting the same philosophy.

But, in adopting it, U.S. managers realized that they could not simply import on a wholesale basis the various means that Japanese firms' used to implement their quality assurance programs. One example indicates why. Contrast the difference in how management objectives for improving quality were conveyed to mid-level managers in the two industries.

In the U.S. case, in order to insure that quality assurance was factored into a line manager's decision-making, it was necessary to explicitly include quality objectives in the job description and identify quality as a major component of a manager's performance bonus. In Japanese firms, the same objective was conveyed by less formal means. Frequent meetings inside the firm and informal socializing outside it conveyed management's intentions to everyone. Collectively, all managers came to understand the need to give weight to these objectives and to move toward achieving them. Further, Japanese managers intuitively understood that high quality was essential for the long-term survival of their company.[24] Consequently, a Japanese firm's process of creating a TQM culture was bound to be based on more informal measures than the comparable process in an American firm.

The Catch-Up With Japan

In order assess the extent of the changes in the U.S. industry practices, first, we will examine how these firms reoriented their investments in quality. Results of a National Institutes of Technology and Standards (NIST) survey of the U.S. semiconductor industry's quality assurance investments in the 1980s provide this insight. Second, we examine more specifically what actions were taken by various firms in the industry to restructure their quality assurance efforts.

Magnitude of the Restructuring of the Quality Assurance Effort

The NIST survey revealed that, between 1980 and 1990, the surveyed semiconductor firms doubled their rate of spending related to quality.[25] (See Table 2.) In isolation, this means little since it could simply indicate that these firms just intensified their investment in Stage One or Stage Two activities such as final test. That the increase reflected a more sweeping change was indicated by survey respondents' answers to questions which probed *where* the increased quality-related outlays were made. The NIST survey asked for the relative quality-related spending across four budget categories: operations, overhead, research and development (R&D) and capital investment. Responding companies reported a substantial decline in the portion of the operations and overhead budgets related to quality (see Table 3); these declines were exactly what one would expect as firms moved away from Stages One and Two towards Stages Three and Four. These latter two stages diffuse quality assurance responsibilities throughout the organization. As a result, spending for overhead functions such as a quality control staff or operations such as final inspection decrease. At the same time, the NIST survey results showed a significant increase in the share of R&D and capital investment outlays supporting quality-related activities. Increases in quality-related spending in these two budget categories were consistent with a move towards Stage Three methods of prevention. Prevention would entail increased emphasis on development and design of products and processes for improved manufacturability and increased reliability.

The NIST survey results also indicated a shift in the management objectives that quality-related outlays were targeted to support. Traditional management objectives, such as improving product performance, showed relative declines. At the same time a completely new objective of "education and training" surfaced. (See Table 4.) These shifts, especially in favor of increased training and education, indicated how the increase in quality-related outlays flowed toward a broad set of objectives in line with those observed in Japanese firms.

<u>Evolution of U.S. Quality Assurance Strategies</u>

In moving towards adopting the comprehensive approach used by the Japanese towards quality assurance, U.S. firms faced a number of significant issues. These issues ranged from how they organized their quality control organization and defined its mission, to how they rewarded their mid-level line managers, to how they trained their line operating personnel, and, most importantly, to how they dealt with outside suppliers. Each one required special attention; otherwise, the overall drive toward improved quality would not succeed. For instance, most firms had their quality control (QC) group organized along classic lines. The QC group was a stand-alone organization responsible for outgoing quality through final test and qualification. This form of organization reinforced a Stage One approach to quality and minimized the role of manufacturing and other operating departments.

Closely related to the issue of organizational form were the management priorities of mid-level operating managers. Their priorities were significantly influenced by the criteria used in their periodic management reviews. Typically the criteria used to grade the performance of these mid-level managers did not explicitly identify quality as a important management objective. Line personnel were also not integrated into the process of quality improvement. In contrast to Japanese practices, U.S. line operating personnel were not given clear responsibilities that included quality assurance broadly defined in the Japanese sense; neither was training of line personnel. Lastly, there was also a problem with the treatment of outside vendors. Sharing of sensitive data on new process recipes with outside vendors was practically verboten -- exactly the opposite of the usual protocol in Japan.

The process of reaching the Japanese standard of performance mandated similar adjustments both in internal management practices as well as changes to the external relationships.

Changes in Internal Organizational Practices

The requirements of meeting the challenge of attaining Japanese style "total" quality assurance led to major organization changes. These changes broadened the responsibilities for quality assurance and emphasized manufacturing as the centerpiece for quality. The nature of these changes can be illustrated with four examples: (1) how the

Quality Control (QC) organization was reorganized and its mission redefined; (2) the diffusion of QC-related responsibilities firmwide; (3) changes in line operator training; and (4) the institutionalization of greater discipline in manufacturing and related management decision-making. The first three examples relate to how responsibilities for quality assurance were broadened.

Organizational Structure. The traditional QC organization had typically been responsible for carrying out inspection and monitoring outgoing quality levels. As U.S. quality assurance philosophy moved more towards Stage Three Prevention in the mid- to late-1980s, the QC organization was decreased in size and its mission statement revised. At AMD, for example, in the late 1980s:

> ...dependence on a classic quality organization decreased. The job responsibility shifted to operations while the quality organization became responsible for auditing, acting a facilitator with a link to the customer, and essentially measuring the effectiveness of the organization in meeting the corporate emphasis on quality.[26]

Redefining Line Managers Goals. In conjunction with the changed focus of the QC organization and its mission, responsibilities for quality assurance diffused broadly through all parts and across all levels of the organization, aligning U.S. management's decision-making culture more closely with that of the Japanese. Everyone in the company would participate in achieving improved quality. Line manager's performance bonus scoring systems were altered to include an explicit quality assurance element. For example, at Harris Semiconductor:

> Quality is [now] given a definitive weight for line people in terms of incentives and bonuses....Something like 10 to 20 percent of a bonus may be dedicated as a reward for quality, for effective implementation and use of SPC.[27]

Increased Investment in Operator Training. The installation of SPC practices necessitated increased investments in operator training. According to the NIST survey, by the late 1980s about 15 percent of the surveyed companies' quality-related investments flowed into this area -- a substantial increase since 1980. (See Table 4.) Despite the increased training for operators, there were major differences between the U.S. and Japan. While the increased operator training sought to mirror the investment of Japanese firms in this area, even today U.S. firms do not match up well against their Japanese competitors. For instance, many U.S. firms stopped far short of defining the job descriptions for line operators as broadly as Japanese firms. Further, American firms typically recruit personnel to work on their fabrication lines who have a higher level of educational attainment than those in Japan performing equivalent jobs. These differences exist because U.S. firms confront a far higher level of attrition in their operator work force and, at the same time, traditionally have found it difficult to recruit high school graduates with sufficient educational attainment needed to fill operator positions. This area has been and continues to be a weak point relative to Japanese firms.

Discipline in the Organization U.S. managers who became familiar with Japanese manufacturing practices in the early 1980s recognized the greater degree of organizational discipline. Greater discipline meant, for example, tighter control over process specifications and closer coupling between designer engineers and process engineers to ensure that a product's design optimized a production line's performance. Thus, greater discipline was essential to achieving long-run improvements in quality assurance.

U.S. firms with manufacturing operations in Japan, such as TI and Motorola, were the first to fully appreciate the importance of instilling Japanese-style organizational discipline in how they evolved manufacturing process and operating conditions. The lessons of greater discipline were not always easy ones to learn. In one case TI transferred the manufacturing knowhow for a leading edge memory product from its production line located at Miho, Japan to a line at Dallas, Texas. The Dallas line was supposed to be an exact duplicate of the Miho line. The manager of the U.S. line, however, decided to "tweak" the Miho process -- a decision that ulimately cost months in delays as unforeseen problems arose in getting process conditions stabilized. The U.S. manager was finally removed and replaced by a TI-Japan manager who quickly stablized the line by restoring the original process conditions.

For other U.S. firms, such as Intel, AMD, and National, who did not have the same type of window on Japanese manufacturing practices, the learning process took place through other channels. Some learning developed out of relationships with Japanese joint venture partners, but an equally significant means came from participation in a manufacturing consortium called SEMATECH established by fourteen U.S. semiconductor firms. Upon its inception in 1988, SEMATECH began to play an important role in encouraging U.S. firms to impose greater discipline in their manufacturing operations. For example, based on its participation in SEMATECH, National Semiconductor decided to centralize all process development activities into a single facility. All of the manufacturing processes run at National's different manufacturing plants gradually were required to conform to process specifications established by the central development group. No modifications by the engineers at the manufacturing lines were permitted without its approval.

Achieving greater discipline required that U.S. managers change their management philosophy to "force teamwork and not allow independent actions."[28] An Intel manager explained the role of greater organizational discipline in quality assurance at Intel as follows:

> There's [a need for] tight control over operations -- no 'tweaking' of the process steps is permitted....If you don't approach improvements systematically, you don't know why you're getting improvements....There is a greater degree of inter-relationships among different elements [of the manufacturing process] -- the same processes are used across different product lines. Communication is enhanced and simplified by the discipline over the organization. It does not require more overhead, rather less. For example, before [we] had planners in each operating group (with the product group, the fab, the test group, and the assembly operation). Now [we] have centralized the planning operation and this has stabilized the operating plan. Overhead has been reduced by centralizing the functions -- every group gets some part of the responsibility for balancing the overall plan....Job descriptions were expanded as part of the decentralizing of the responsibilities.[29]

A senior executive at Harris Semiconductor summed up the implications of greater discipline for the U.S. industry as follows:

> Ten years ago...the issue was who could hire the best and the brightest product design engineer. An answer does not lie [today] in individual contribution to a company or relying on expertise in one area. Rather, the team/systems approach wins in today's [integrated circuit] house.[30]

An executive at TI, describing the change in their quality assurance philosophy in the 1980s, provides a good summary of the changes that were instituted at the U.S. semiconductor firms who led the way in closing the quality gap:

> A shift in TI's definition of quality initially took place in 1980-1981. [We] used to look at quality in terms of PPM product defects. However, [our] definition of quality radically evolved into one of total quality performance and customer defined quality (which includes every part of the interface....Things such as the following are included in the concept of quality: management decisions, customer interface, vendor interface, and total quality control. Quality is not a segmented function for most employees, but an integral part of virtually everyone's performance criteria.[31]

Changes in External Relationships

No aspect of the Japanese quality-driven strategy was more difficult for U.S. semiconductor firms to emulate than the Japanese style of having extremely close relationships with external vendors. While U.S. firms could seek their own way of adapting Japanese manufacturing quality objectives into their own organizations, the process of changing their external relationships was far more difficult. At first, U.S. firms sought to instill into their vendors a common set of quality objectives together with a harmonization of practices by winnowing the number of suppliers down to a select few designated as "best in breed." Intel, for instance, explained the idea:

"We have no commodities with more than three suppliers; more frequently we have only two suppliers. Sometimes we'll go with a single supplier, but if we do that, we make sure it's a supplier with dual factories or with dual tooling. [Simultaneously,]...there has been an increase in resources in the procurement process, and a larger portion of management dedicated to quality of incoming material. This is how procurement management is evaluated."[32]

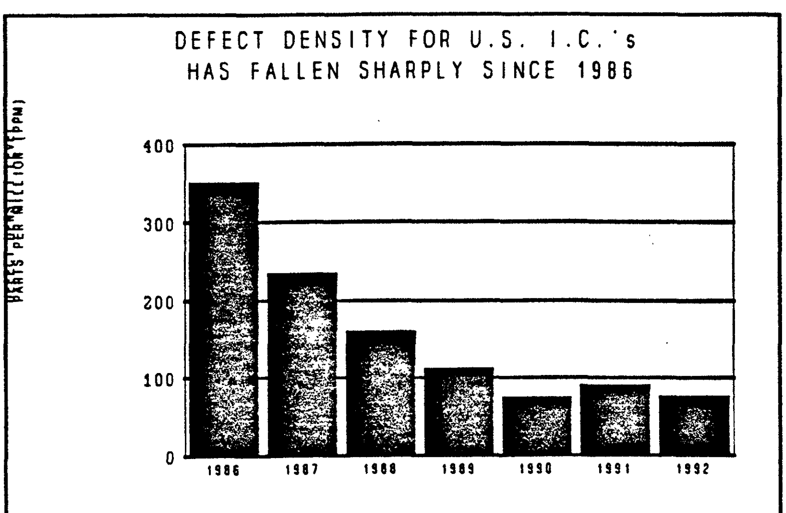
But working with a more limited set of suppliers, with greater management attention still fell short of the degree of integration that Japanese firms took to be the norm. The solution to how to achieve the required degree of close coupling in external relationships ultimately fell to SEMATECH.

SEMATECH's original mission was to address the need to develop leading edge process technologies for U.S. firms. But a by-product of SEMATECH's creation was to provide a means of breaking down the barriers to developing tighter, almost Japanese-style, customer-vendor relationships.[33] For example, while Japanese device firms had for years routinely shared details on their most advanced processes with key equipment and materials vendors, such a degree of sharing was a rare exception in the U.S.[34] SEMATECH began to change that. First, SEMATECH provided a vehicle for technology exchange with the vendor base by presenting information on the broad technical roadmaps the major device firms were pursuing. Further, SEMATECH indirectly encouraged the sharing of detailed process information. Today, details on future processes are more frequently shared so that vendors can participate in the specification of future process requirements.

SEMATECH has been such an effective instrument in improving the development of U.S. technology roadmaps that Japanese semiconductor executives are now closely studying SEMATECH's operating procedures and are considering whether they should create a similar entity in Japan.[35]

Is The Quality War Over?

The payoff from the U.S. industry's increased emphasis on quality assurance investments began to manifest itself by the mid-1980's. The average rate of product defects fell from 760 PPM in the early 1980s to less than 400 PPM by 1986. The decline in the defect rate continued steadily. By 1990, the rate fell below 100 PPM, see Figure 1, a rate in line with that being achieved by the best Japanese producers.[36]



Source: Semiconductor Industry Association, quarterly quality survey

While it would be an overstatement to claim victory in the quality war for all U.S. semiconductor producers, the efforts of the leading edge companies clearly paid off. No longer can it be claimed that, from a quality standpoint, the leading firms are only located in Japan. In fact, by 1989, H-P, who started the drive to improve quality in the U.S. semiconductor industry in the early 1980s, noted that the best U.S. firms were equaling the level of the best Japanese firms.[37] Even Japanese observers seem to acknowledge this.[38]

Undoubtedly the improvement in U.S. quality helped lay the foundation for the striking recovery in the global market share held by U.S. firms.

What lessons should be derived from all this? First, superior quality is not a Japanese cultural mandate. U.S. firms, too, can successfully implement a total quality philosophy.

Second, in the wake of the U.S. semiconductor industry's effort to follow Japanese practices there has been a blurring of what used to be sharp distinctions between the general management and organizational practices in the two countries. Internally, the Japanese have adopted practices that put a heavy emphasis on maintenance, training, and selective automation to support their quality assurance goals. Leading edge American firms have followed this general approach.

However, the degree of tight coupling between the Japanese semiconductor producers and their vendors is something American firms are still working to create. SEMATECH proved to be a novel new approach to facilitating change in the traditional form of vendor-customer interaction in the U.S. Traditional Japanese business practices facilitate an extremely close set of working relationships among different firms, and it is unlikely that American firms will ever totally emulate Japanese practices in this area. But increased Japanese interest in the role that SEMATECH plays in establishing common technical roadmaps throughout the industry suggests that SEMATECH's leverage may be substantial. The lesson here would seem to be that the West need not emulate all aspects of Japanese organizational and management practices in order to be competitive.

For other U.S. industries facing intense international competition the lessons to be learned from the experience of the U.S. semiconductor industry are several. Study and learn from your competitors, but copy smart. When Western management practices inhibit outright copying, search for a new means to effect similar outcomes. Sometime the results can even be superior. Blind copying of Japanese practices is not needed to be successful. Rather, thoughtful adaptation is essential if broad Japanese principles are to be inserted into practice in the U.S. with real weight.

TABLE 1

The Four Stages In The Evolution Quality Control Practices In The U.S. Semiconductor Industry

Stage 1 Inspections and Verification This philosophy toward quality assurance permeated the U.S. semiconductor industry in the 1960s when the U.S. military market was the single largest market in the world for ICs. Strongly influenced by the U.S. Department of Defense procurement philosophy of inspection and verification inserted into the industry in the 1960s, firms relying upon this approach would "inspect everything." To verify life cycle reliability, stress tests and sometimes destructive testing were the means used to verify conformance to military specifications (Mil-Specs).

Stage 2 Appraisal The "heavy on inspection" philosophy evolved toward an appraisal system that emphasized measurement, evaluation, and auditing of final product quality, as well as insuring that purchased components and materials conformed with quality standards and performance requirements.

Stage 3 Prevention A more robust approach to quality assurance than appraisal that involves major changes in management philosophy, such as designing quality into the product, application of Statistical Process Control (SPC) techniques to manufacturing operations, and shifting the responsibilities for quality assurance into the operating organizations. Conventional quality assurance organizations decrease in size and importance in firms applying this approach.

Stage 4 Total Quality Management (TQM) TQM is an approach to quality assurance that seeks to completely emulate the Japanese management philosophy of quality assurance. It incorporates all of the elements of prevention, but goes on to a broader concept. Quality assurance becomes the responsibility of all levels of management and employees, while relationships with vendors and customers are aligned to reflect and support the total quality philosophy.

Table 2
Estimated Percentage of Total Company Outlays Directly or Indirectly Allocated Towards Achieving Quality
(Percent)

Average, 1980-1985	1990
10-20	20-35

Source: NIST survey of 11 U.S. semiconductor firms.

Table 3
Percent of Company Outlays Related to Quality
Within Major Budget Categories
(Range of Percentages Reported)

Budget Category	Average 1980-1985	1990
Operations	25-70	10-25
Overhead	20-50	10-60
R&D	0-5	5-40
Capital	0-10	10-60

Source: NIST survey of 11 U.S. semiconductor firms.

Table 4
Allocation of Company Quality-Related Outlays By Management Objective
(Percent)

Management Objective	Average 1980-1985	1990
Improving Product Performance	45	30
Reducing Attribute Variability	15	25
Increasing Product Reliability	5	20
Improving Manufacturability (Improved materials and processes)	35	10
Other (Education/Training)	N/R	15
Total	100	100

Source: Average response from NIST survey of 11 U.S. semiconductor firms.

1.This article is based in part on three earlier studies by the author. The first, prepared for the National Institute of Standards and Technology, "U.S. Investment Strategies for Quality Assurance," the second, "The Effectiveness of the Japanese R&D Cycle: Engineering and Technology Transfer in Japan's Semiconductor Industry," and the third, "Advanced Equipment Development in Japan's Semiconductor Equipment Industry"; the last two studies were co-authored with Jeffrey Frey for the Semiconductor Research Corporation. Views expressed in this article are solely those of the author.

2.Source: DATAQUEST, a semiconductor industry market research firm.

3.There are a number of benchmarks that can be used in the semiconductor industry to measure quality, such as the yield of good parts in production or the turn around time in delivery, but the rate or percent of defective parts actually shipped is recognized in both Japan and the U.S. as the best overall measure. There are several reasons to prefer the PPM measure over other measures. First, yields, the percent of good product produced, varies from product to product and company to company for reasons completely unrelated to quality. For example, if one company produces devices of a very simple design with older design rules, its yields would tend to be higher than those of another firm producing newer, more complex devices with aggressive design rules. Second, company-specific data on actual yields achieved or turn around times are a closely held secret making overall comparisons difficult to make between Japanese and U.S. firms.

4.PPM data can be reported either for outgoing quality or for incoming quality, that is, at the customer level. The PPM data presented here is for outgoing quality, except were noted.

5.Data on incoming PPM levels supplied to the author by Hewlett Packard.

6.Data on U.S. defect density Semiconductor Industry Association Quarterly Quality Report survey for defect density for all MOS devices. Data on Japanese PPM taken from translation of *Nikkei Electronics* article, "User, Manufacturer Cooperation In Quality Assurance," June, 1988, which states: "In the case of 256K DRAM memories, the average failure rate is about 100 PPM." Another *Nikkei Electronics* article in the same month reported the acceptable range for defects to about 100 to 200 PPM.

7.At that time, the U.S. semiconductor customer base consisted of three tiers. The first tier, mainly the main frame computer and high-end business equipment makers, were the most quality conscience. The Japanese companies concentrated on qualifying their products with these firms in order to establish their position as high-quality producers.

8.Fujikawa, et al., "Evaluation on the Quality of Semiconductors from the Users' Point of View,", Quality Engineering Department, Engineering Division, Matsushita Communications Industrial Co., Ltd, June, 1982; p. 14.

9."Total Preventative Maintenance," Translation of paper prepared by NEC, Yamagata facility management, presented at Super LSI Ultraclean Symposium, No. 6, Tokyo, Japan, June 1988.

10."Current Status and Problems of IC Production Facilities," Translation of paper presented by Fujitsu, author unknown, at Super LSI Ultraclean Symposium, Tokyo, Japan, June 1988.

11.H. Horikiri, "Current Status and Problems of Production Systems," Translation of paper, LSI Production Headquarters, NEC, undated.

12.Interview with K. Kurokawa, Fujitsu.

13.Based on author's interviews with managers in Japan and the U.S.

14."Total Preventative Maintenance."

15.An example of the U.S. views on the benefits of automation can be found in the statement of M. Shopbell, AMD, "Equipment Automation," Information Services Seminar, Semiconductor Equipment and Materials International, 1985, p. 239.

16.H. Horikiri, p. 8.

17.Jim Freedman of IBM and Robert Learch of Monsanto conducted an informal study of this feedback system in Japan and concluded that it was far more thorough and intensive than any comparable degree of interaction among U.S. firms.

18.The author together with Professor Jeff Frey extensively studied the relationship between Japanese device and equipment firms.

19.Fujikawa, p.2.

20.Based on interviews conducted by the author in Japan with equipment vendors and semiconductor firms. Several equipment firms noted that they are never pressed to the same extent to supply information by American firms nor asked to work with the American firm to assess new process developments.

21.J. Freedman and R. Lerch, "Analysis of Specification Requirements of U.S. and Japan Semiconductor Fabricators," unpublished paper prepared for the Semiconductor Industry Association of Japan, 1986.

22.DATAQUEST global market data for DRAMs.

23.DATAQUEST.

24.Since the 1950s, there had been a number of groups established in Japan such as the Japan Productivity Center whose mission included promoting quality assurance improvement. These groups fostered a broad understanding among Japanese managers of the importance of quality in determining overall competitiveness.

25.Among the firms covered by the NIST survey were: TI; AMD; Intel; Harris Semiconductor; LSI Logic; National Semiconductor; and VLSI.

26.Author's interview with Wayne Cantu, AMD.

27.Author's interview with Sharon Sines, Vice President Quality Assurance, Harris Semiconductor.

28.Author's interview with Sharon Sines.

29.Author's interview with Steve Sillyman, Intel.

30.Author's interview with Sharon Sines.

31.Author's interview.

32.Author's interview with Jim Watson.

33.Though not in the original strategic plan for SEMATECH, the SEMATECH mission quickly became expanded to encompass an effort to sustain the viability of U.S. semiconductor equipment and materials suppliers. An adjunct association called SEMI/SEMATECH was established in 1988 to liaison with the equipment and materials industry. This organization played an important role in subsequent years in developing stronger ties between device firms and their vendors.

34.Author's interviews with U.S. and Japanese managers in the semiconductor industry.

35.Author's interviews with Japanese semiconductor executives, 1992.

36.*Nikkei Electronics*, June, 1988.

37.The quality director at H-P was quoted in 1989 to have stated: "On the one hand, Walter [quality director at H-P] said he is encouraged by how many U.S. companies have improved the quality of their products, but he is depressed to see so many that have not. He said the best U.S. chip-makers are now on a par with the best of the Japanese, but, on average, quality in the United States still is not as high as in Japan." *Electronic Buyers' News*, Sept. 4, 1989, p. 44.

38."LSI quality varies according to the manufacturer and the type of LSI. LSI quality also differs according to the manufacturing plant, even in the case of the same manufacturer and type of LSI...Even LSI manufacturers determine LSI quality according to the users' requirements. In other words, LSI quality varies according to the manufacturer." *Nikkei Electronics*, June, 1988.