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Japanese and U.S. Semiconductor Firms Bridging the Knowing-Doing Gap on the Shopfloor

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Abstract

This case on problem-solving in the semiconductor industry focuses on bridging the knowing-doing gap on the shopfloor. We present a variety of examples of problem solving structures and organizations in semiconductor firms in Japan and the U.S. We find that while there are large differences in each firm's specific organization and problem-solving structures, Japanese firms tend to demonstrate a firm-wide problem-solving philosophy where putting knowledge into practice starts at the top and cooperative problem solving is encouraged. The structures at U.S. firms are consistent with a learning-by-doing model where failure is not penalized and immediate action is valued over extensive planning.

Introduction

This study focuses on bridging the knowing-doing gap through problem-solving on the shopfloor in the semiconductor industry, where the continual solving of problems is critical for improving quality and lowering costs. To analyze the knowing doing gap, we examine Pfeffer and Sutton's Eight Guidelines for Putting Knowledge into Practice[1] and how these guidelines are implemented in the semiconductor industry.

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[1] The guidelines are adapted from Pfeffer and Sutton," Knowing 'What' to Do Is Not Enough" *California Management Review* Fall 1999.

We first describe the eight guidelines for putting knowledge into practice and then we look at how these guidelines are implemented in real world problem solving situations. We find that in the companies we have studied there is much variation in specific problem solving systems, but on the whole, the structures of the Japanese firm demonstrate a strong firm-wide problem-solving philosophy where putting knowledge into practice starts at the top and cooperative problem solving is encouraged, and the structures of the U.S. firm are consistent with a learning-by-doing model where failure is not penalized and action is valued over planning. These results come from studying a small sample of firms in each country and may not be generalizable to the industry as a whole, or to the economy as a whole.

Companies that successfully put knowledge into action have total organizational commitment to that goal. Companies must reward action at all levels of the organization and create systems that support action. The optimal systems for putting knowledge into practice should have the following characteristics:

Eight Guidelines for Putting Knowledge into Practice

1. Doing reinforces knowledge.
   - Systems that require workers to learn by doing will force workers to associate their new knowledge with action and as a result, the knowledge will no longer be separated from action.

2. Doing anything is more important than creating an elegant plan ("Ready, Fire, Aim").
   - All actions should be consistent with achieving a goal or solving a problem.
   - "Ready, Fire, Aim" means describe the problem to solve, act on a potential idea to solve the problem, assess the outcome of the actions and prepare for the next potential solution.

3. Don't penalize failure.
   - Workers will be unwilling to take risks and disrupt the status quo if they will be penalized for failure.

4. Minimize fear in the corporate culture.
   - Workers need to feel secure in their jobs to accept the personal risks of putting knowledge into practice and disrupting the company status quo.

5. Cooperate within the organization.

    - Cooperation within the firm encourages innovation and efficient use of resources.

6. Measure what is important.
    - It is important to keep goals clear and concise. One way to ensure this is to limit the number of items that are measured.

7. Corporate philosophy is important.
    - The systems where workers are encouraged to put knowledge into practice need to fit into a supportive corporate philosophy.
    - Although business environments are highly flexible and thus strategies and systems need to remain flexible, an underlying corporate philosophy should be resistant to change.

8. Putting knowledge into practice starts at the top
    - Putting knowledge into practice requires full organization commitment from the top leadership downward.

In the next section we present a variety of problem-solving examples from the semiconductor industry. For each example we analyze how the eight guidelines for putting knowledge into practice are implemented.

Examples of Problem Solving

The previous section has examined the corporate structures necessary to put knowledge into practice. Here we present a set of short examples of advanced problem solving from Japan and the U.S. that illustrate how a variety of firms use these structures effectively.

Examples from Japan:

Example 1:

An engineer in the etch division of a Japanese fab identified a sudden increase in the number of defects occurring during a specific processing step. When he runs into a problem that may be similar to problems at other fabs in the company, it is standard operating procedure to contact the engineers at corporate headquarters to notify them of the issue and discuss potential solutions.

In his experience, about half of all problems that he reports to headquarters have been solved before or can be solved easily by the experts there. For the other half, he works with headquarters to identify what data to collect and what steps to take. Additionally, he meets with the engineers at headquarters to learn about the problems at other fabs as well as advancements in technology.

In addition to gaining knowledge from his colleagues at other plants in the company as distributed through the corporate headquarters, he also collects information on how to solve problems through academic journals. He is not allowed to collect information form engineers at other firms. His only channel to access knowledge of other firms is through academic and trade journals.

After discussion with the engineers in the corporate office, he and a development engineer assigned to work with him on the project developed a plan to collect data on the problem. They increased data collection at every phase of the process to identify exactly where the problem occurs in the process and exactly which lots of wafers were affected. They quickly identified a leak in a gas line that was causing the defect problems. They fixed the leak and modified procedures to minimize the risk of the leak recurring. Upon completion of the process they communicated their steps and solution to the engineers at corporate headquarters.

Analysis:

In this example, the Japanese firm implements many of the basic tenets for bridging the knowing-doing gap. Specifically, the company provides a great example of the value of the following guidelines: "Doing reinforces knowledge", "Cooperate within the organization", "Measure what is important", "Corporate philosophy is important", "Putting knowledge into practice starts at the top".

The corporate problem-solving philosophy of this firm is designed to promote cooperation within the organization and to involve engineers at the top of the company. The integration of engineers at corporate headquarters into the problem-solving process indicates that putting knowledge into practice is important at the top of the organization.

This system also maximizes knowledge within the organization by providing formal structures to transmit knowledge throughout the firm. For example, the engineer in the study notes that about half of the problems he discusses with corporate headquarters are problems that have been solved before at other fabs or can easily be solved by the experts at headquarters. At most other firms, there is not a formal channel to distribute knowledge between fabs, and identical problems are solved from scratch multiple times. Starting from scratch greatly increases the time necessary to bridge the knowing-doing gap, so having a formal channel in place to distribute solutions to problems is a great competitive advantage. Once the knowledge is distributed from headquarters and the engineers on the shopfloor implement the knowledge, learning is reinforced and the engineers are unlikely to need support from headquarters the next time they face a similar problem.

Not only is there cooperation with engineers at corporate headquarters, there is also cooperation between different types of engineers on the shopfloor. The involvement of different types of engineers allows the team to identify the most important data to collect and then to analyze the data using a variety of different skill sets.

Example 2:

At another Japanese fab, an engineer in the Deposition area was told by his supervisor that the "up-time" (the time that a machine is functioning properly) on one of his tools was inadequate. He was aware that this was an on-going problem, but was now worried about disappointing his supervisors and colleagues. The machine was new to the fab and it was one of their first tools on a whole new geometry process. With the new process, there were many bugs to work out and few people in the firm with experience solving these new problems.

In order to increase up-time, the engineer first called a meeting of selected engineers, operators, and technicians in the area. They were each assigned to explore different facets of the tool in which they were experts, to identify potential problems and ways to increase up-time.

In addition, they contacted the equipment vendor for additional support. The vendor discussed a variety of new issues to be concerned with when working with the new process and helped the different team members design methods to study the functioning of the machine.

This is an on-going project and the team is continuing to work very closely with the vendor to learn as much about the new machine as possible.

Analysis:

As in the prior example, this fab demonstrates a great degree of cooperation within the organization and provides an example of how corporate philosophy is important. Additionally, the team of problem-solvers on the shopfloor focused on measuring what was important.

The corporate problem-solving philosophy in this firm is marked by assigning cross-functional and cross-occupational teams to work on problems. Each team member is encouraged to focus on the aspects of the problem in which they have expertise. The team then cooperates together to synthesize the ideas and knowledge of the diverse set of experts. The team is also encouraged to cooperate with vendors in order to bring outside knowledge in to the group.

Each team member collected the data they thought was most important. This approach has trade-offs. To avoid "paralysis by analysis" where access to too much data slows the problem-solving process, it is often important to limit the amount of data collected. In this example, each team member collected a manageable amount of data, but collectively, they may have an overwhelming amount of data to analyze.

A weakness in the problem-solving structures at this firm is the presence of fear in the problem solving process. The primary engineer in the example was told by his supervisor that the performance of his machine (which directly reflects his performance) was unacceptable. This created a stressful, fearful environment for the engineer. Although this engineer responded well to the stress, this is not always the case.

Examples from the U.S.:

Example 1:

At a U.S. fab, a development engineer in the Deposition area noticed a problem with a delivery system for liquid chemicals. The system was very far out of spec which led to frequent fluid change procedures. The fluid change procedure is expensive and time consuming. Because the fab only had two tools at this processing step, having the system down was a major bottleneck in the fab.

One of the difficulties in addressing this problem is that the delivery system was new to the fab, thus there was not an existing body of knowledge on the tool, and the engineer did not know whether the tool itself was faulty or their implementation of the tool was faulty.

The engineer hypothesized that the cause of the problem was that a key pump was malfunctioning. His first instinct was to solve the problem through trial and error; however, the material costs necessary for running trials are very high making trial and error prohibitively expensive. Instead, he developed a plan to systematic test the functions of the system without using expensive materials. After exploring all of the possibilities, he was still unsuccessful in eliminating the problem.

At this point, he called the equipment vendor and asked for support. The equipment vendor pointed out that the problem could be a result of the tool, a contaminated batch of chemicals, the procedure, or the computer hardware running the system. Additionally, if contaminated chemicals entered the system, the entire system could be ruined.

The equipment engineer convened a team meeting including the equipment vendor, the materials vendor, in-house equipment engineers and in-house process engineers. Working as a team, they solved the problem in two weeks. The team met every day for the first week and then every other day for the second week. Once they identified that the problem was related to faulty hardware, they updated the hardware and put in a system in which future hardware testing and upgrading would be easier to perform.

The engineer's performance was evaluated on the time it took to solve the problem. If over the course of the year he meets minimum speed requirements on all of his problems, he will receive a bonus equal to a sliding percentage of his salary. The percentage of his salary is determined by his individual overall performance.

Analysis:

In this example, the U.S. engineer demonstrates a problem-solving system that is consistent with the knowing-doing gap guidelines of: "Doing reinforces knowledge", "Doing anything is more important than creating an elegant plan (“Ready, Fire, Aim”)", "Don't penalize failure", "Cooperate within the organization", and "Measure what is important".

The engineer's first instinct was to jump right into the problem and start a trial and error process to identify potential causes and potential solutions to the problem. His instincts reflect the guideline of "Ready, Fire, Aim!". This is often a very effective process because problem-solvers may not solve the problem on their first try, but they learn more about the problem and they learn why their first attempt at a solution failed. This additional knowledge can then be used to develop the next trial where the next trial comes closer to solving the problem. This is an iterative process that should lead the problem-solver to a solution and allow the problem solver to learn throughout the process.

However in this specific case, the engineer realized that trial and error would be prohibitively expensive. Instead of the "Ready, Aim, Fire!" approach, the engineer focused on a strategy of measuring what is important and cooperating within the organization to develop a cost effective plan for approaching the problem.

In this example, there is mixed evidence of the level of cooperation within the organization. Obviously cooperation is an important part of the process because a cross-functional team was convened to study the problem; however, rewards associated with performance at the fab are awarded based on individual performance. This may create competition between team members and undermine a collaborative problem-solving process as team members try to advance their own careers.

The problem-solving structures of this firm do not directly penalize failure and as a result minimize fear in the organization. The firm rewards success and does not penalize those who try to solve a problem, but fail. The compensation for individuals is structured so that individuals receive a base level of compensation and then bonuses are awarded for high performance, with higher performance rewarded with greater bonuses. The down-side risk to an engineer is limited, but the upside can be great.

Example 2:

An equipment engineer working in the Polishing division of another U.S. fab discovered a problem where a piece of equipment was occasionally breaking wafers. The wafer breakage was rare, but each wafer is very valuable so the breakage had to be eliminated. Making the problem difficult to study was the fact that the breakage occurred in a seemingly random fashion. In other words, the breakage occurred very rarely and at unpredictable times, thus it was very difficult to collect data on the problem.

The engineer's first step in solving the problem was to recreate the problem. He spent a great deal of time running blank wafers through the machine at different settings to try to recreate the breakage. He was unsuccessful using this trial and error style approach.

His next step was to create a data recording system for the operators running the machine. He created a form on which the operators would detail all of the machine settings and other relevant information whenever a breakage occurred.

When he had collected a sufficient volume of data he asked his manager to create a team to help solve the problem. The manager appointed process engineers, equipment engineers, operators, and technicians to the team, but the original engineer still has total ownership of the project. He was the leader and had final responsibility in finding a solution.

The team met twice a week during shift changes in order to include participants on both shifts. At each meeting, they brainstormed a variety of potential causes to the problem. After coming up with ideas, they would develop methods to test their hypotheses and then perform these tests.

After several weeks, they discovered that the wafer handling procedure was not sufficiently well-defined and that the breakage problem was attributable to how wafers were loaded into the tool. They rewrote the wafer handling specs and trained the operators in the new methods. The team was so successful on this project that the manager has encouraged them to continue meeting to explore other materials loss problems in the fab. Team members received a bonus based on their individual role in the project and the total costs the team saved the company.

Analysis:

This U.S. firm demonstrates very similar problem-solving structures as the other U.S. firm. The example demonstrated the following guidelines in bridging the knowing-doing gap: "Doing reinforces knowledge", "Doing anything is more important than creating an elegant plan (“Ready, Fire, Aim”), "Cooperate within the organization", "Measure what is important", and "Corporate philosophy is important".

As in the prior example, the engineer's first instinct was to immediately initiate a trial and error process. In this case, the engineer used the "Ready, Fire, Aim" approach to try to recreate the problem. The thought process of the engineer is that by learning how to create the problem, one can learn how to prevent the problem.

Attempting to recreate the problem is consistent with the guideline that "Doing reinforces knowledge". The engineer was learning about the problem by doing what was necessary to create the problem. In the process of doing, the engineer reinforced his knowledge of the tool, of potential problems, and of potential solutions. Ultimately, this approach was not directly successful, but this does not minimize the extent of the knowledge gained and reinforced through the trial and error process.

The engineer's next step was to measure the factors that are important. The engineer instituted a new measuring and documentation process that was specifically designed to collect information that would help solve the problem.

In this firm, the mixed message of cooperation at U.S. firms is even more evident than in the other U.S. example. The engineer's supervisor promoted cooperation by assigning a team to assist the engineer but the supervisor made it very clear that the engineer was in charge of the team and was responsible for the performance of the team. Additionally, performance bonuses are assigned based solely on individual performance. These structures create a situation where there is great incentive for individuals to compete and not share the credit of team projects.

Conclusion

While we find that there is much variation in specific problem solving systems in the companies that we have studied, the structures of Japanese firms tend to demonstrate a strong firm-wide problem-solving philosophy where putting knowledge into practice starts at the top and cooperative problem solving is encouraged, and the structures of U.S. firms are consistent with a learning-by-doing model where failure is not penalized and action is valued over planning.

Strengths of Problem-Solving Systems at Japanese Semiconductor Firms:

- **Cooperation within the organization**: Both firms mentioned in this study implement a strong team-oriented approach to problem solving. Teams are the basic unit of problem solving. Teams are typically cross-functional which allow complex problems to be approached from a variety of different angles and allow the team to understand the ramifications of any process or equipment alteration on other processing steps.
- **Data Collection**: The initial step when presented with a problem is to collect data on the problem. This is very important for understanding the problem, prioritizing potential solutions and measuring the effectiveness of solutions. However, it is important to focus on measuring what is important. Some firms in the industry may collect too much data which slows down the process of putting knowledge into action.
- **Prevalent and strong corporate philosophy**: Both Japanese firms mentioned in this study have a strong corporate culture that outlines the structure of problem solving. This corporate philosophy may manifest itself in formal channels for cooperation, or team building, and it may also manifest itself in how workers cooperate and are rewarded for cooperation.
- **Innovation and problem-solving starts at the top**: Engineers at corporate headquarters are often involved in the problem solving process. This allows the best engineers at the company to interact with many young fab-level engineers and it also allows for an efficient use of knowledge within the firm as few problems are necessarily solved from scratch. Involvement of senior engineers at headquarters allows the corporate philosophy on problem solving to be reinforced through out the organization.

Strengths of Problem-Solving Systems at U.S. Semiconductor Firms:

- **Learning by doing**: In both examples, the problem-solver's first instinct in bridging the knowing-doing gap is a trial and error style approach. By definition trial and error implies trial of some activity. This may not directly solve the problem, but it reinforces knowledge of the problem and of potential solutions. Trial and error is a powerful iterative process that reinforces learning and bridges the knowing-doing gap.

- **Ready, Fire, Aim!**: Consistent with the trial and error process, U.S. engineers are likely to start implementing actions before they formulate an elegant plan. The "Ready, Fire, Aim" approach insures that actions will be undertaken and that problem solvers avoid the "paralysis by analysis" trap where so much effort is put into developing a plan that actions are put off indefinitely. The "Ready, Fire, Aim" approach can often be costly, but it is very effective at transforming knowledge into action and leads to acquisition of new knowledge.

- **Failure is not penalized**: The U.S. firms both have compensation systems and performance evaluation systems where success is rewarded, but failure is not directly penalized. They typical incentive system at a U.S. firm includes a base salary which is paid independent of performance (although consistently poor performers will have their employment terminated), and then a sliding scale of bonuses where bonuses are directly related to individual performance. This compensation format removes the risk of occasional failure and provides an incentive for individuals to attempt to solve high-value, high risk projects.

- **Fear is minimized**: Because occasional failure is not penalized, there is very little fear of failure in these U.S. organizations. Engineers are encouraged to try to new projects and are encouraged to develop creative solutions to problems. If the engineer's solution is occasionally unsuccessful, there is very little fear of reduced compensation, termination, or loss of colleagues' respect.