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This case study focuses on how firms structure their human resource and knowledge systems to support knowledge acquisition and problem solving by their engineers, especially those in research and development. We use results from a unique survey of engineers in three Japanese and two U.S. semiconductor companies to describe the basic characteristics of the Human Resource (HR) Management and Knowledge Management (KM) systems for engineers in this industry.

From our fieldwork in the semiconductor industry over the last decade, we observed differences in how companies are organized internally and how they interact with the external technical community. We conducted a survey of engineers in order to explore how companies vary in their “external” as opposed to “internal” orientation of their HR and knowledge systems. Following the argument of Henry Chesbrough in *Open Innovation*, we hypothesize that HR and knowledge systems with a relatively external orientation allow R&D engineers better access to leading-edge technology than systems with a relatively internal orientation. The statistical results presented below show that the two U.S. companies have a more external orientation of the HR and Knowledge Management Systems than the three Japanese companies.

The Sample

Although our limited sample is not representative, it provides profiles of the systems that are consistent with our extensive fieldwork at semiconductor companies in Japan and the United States. Here the respondents, who are engineers in R&D and fabrication facilities (fabs), include 35 engineers from three leading Japanese semiconductor companies and 27 engineers from two leading U.S. semiconductor companies. The surveys were collected during the mid-1990s. They represent what might be considered best practices from the industry in the two countries.[1]

Organizational Structures for Creative Performance

Our conceptualization of the organization systems assumes the HR system has three major components: 1) work organization; 2) training and skill development; and 3) pay and promotion. The knowledge system also has three major components: 1) sources of technical information; 2) communication networks; and 3) intellectual property (IP) controls. As Figure 1 illustrates, the knowledge and HR systems overlap in producing the organizational structure in which engineers solve problems and create new technology. An engineer's activities are situated within the project team governed by these structures. Firms rely on the interaction between their organizational systems and their employees' activities involving problem solving and experimentation, facilitated by their ability to import and integrate knowledge.

Companies creating new products in an industry with short product generations find themselves relentlessly combining new internal knowledge with external knowledge to keep pace with the industry. In the semiconductor industry, knowledge specific to a product generation depreciates rapidly, and the need to create knowledge requires support of individual creative activities. Although the team is still needed to coordinate activities, the team is a less useful structure for training and sharing knowledge (xx Why?). The individual requires autonomy to pursue learning and ideas as he/she creates new knowledge.

[1] The full sample consisted of surveys from 108 integrated circuit (IC) engineers from 1994 through 1998. In addition to receiving responses from IC engineers who work for chip producers, we also received responses from engineers who work for vendors of the manufacturing equipment used in chip plants (46 respondents), as well as engineers who work in other capacities associated with the industry such materials suppliers.

We argue that HR and knowledge systems can be characterized as having an external (i.e., outside the firm) or internal (i.e., within the firm) orientation. The components of the HR system can be described as internal or external according to their orientation to firm-based rules or external markets, respectively, in determining how work is organized, skills are learned, and how pay and promotions are determined. At one extreme an internal HR system relies upon bureaucratic rules to organize work in teams, to train, and to structure compensation by seniority. At the other extreme an external HR system relies upon the external labor market to set pay for individual workers, who are in charge of their own careers and who work independently even within project teams.

The components of the knowledge systems also can be described as internal or external. Internally-oriented knowledge systems rely primarily on private knowledge sources (both personal contacts and documents) inside the firm. When engineers in internal knowledge systems access external knowledge and information, their sources are public in nature (patents, journal articles, reverse engineering, conferences, tradeshows, popular press, and newsletters).

In contrast, we characterize an externally-oriented knowledge system as one that relies on engineers' external private networks with people at other companies and on the company's private collaborative agreements (consortia). We assume that private external sources contain state-of-the-art knowledge, while public sources contain more dated material. The speed associated with word-of-mouth interactions versus the time it takes to codify and then disseminate new technical knowledge also favors external systems for problem solving in rapidly evolving industries. "Super-ordinate relationships" like consortia raise the likelihood of knowledge transfers not only because of scheduled meetings across the partnering companies but also on account of informal relationships that grow out of the formal relationship. The importance placed on internal knowledge sources versus external sources has changed over time. In the past, engineers were reliant on colleagues within their own organizations (Allen 1971), and companies were likely to use a "local language" that impeded the ability of their engineers to communicate effectively with outsiders (Katz and Tushman 1983). Today problems and solutions are not likely to be local in nature as common technology is used across products. Communities of practice and, more generally, "networks of practice," cut across organizational boundaries and link together, for example, engineers in niche technology areas.

Based upon our fieldwork and past literature, we believe that engineers who regularly tap into expertise both inside and outside of their firms and who are supported by an HR system that encourages external ties would exhibit greater creative performance.

Comparing Systems in Japan and the United States

The two countries under study are known for having different national labor market institutions and for occupying different market positions in the industry. Japanese employees are characterized as performing the majority of their work in teams where the building of consensus is important. Japanese firms have struggled to break into high-margin semiconductor markets to move away from their reliance on the low-margin DRAM market. U.S. engineers are characterized as more likely to work independently and to seek career advancement and technical information from their personal contacts outside their firms, which are leaders in the industry, particularly in logic devices.

To some degree, national institutions constrain the firm’s ability to cultivate external or internal knowledge and HR systems. Company control over intellectual property is influenced by national labor market institutions. In Japan, where professional careers are primarily advanced within a company, and alternative opportunities for advancement are limited, engineers and their company share the same goal of expanding and protecting knowledge within the company. Japanese companies, which focus on team performance, are concerned with the long-term development of their engineers and with long-term relationships within the company. With low turnover, they are less concerned about internalizing their engineers’ knowledge and protecting knowledge.

In the United States where professional careers are often advanced through a succession of jobs at different companies, engineers rely on expanding their own knowledge for advancing their careers. In contrast with the situation in Asia, individual engineers have less incentive to expand and protect knowledge within the company. U.S. companies that focus on individual performance are concerned with labor mobility and competing for talented engineers with their competitors. They are less concerned with the development of their engineers than with finding ways to retain their talent, protect their IP, and internalize their engineers’ knowledge within the company. With short product lifecycles, however, the protection of knowledge often is secondary to keeping up with the state-of-the-art.

Here we use the survey results to describe the basic characteristics of the HR and Knowledge systems for engineers in major semiconductor companies in the two countries.[2] Although our sample is not representative, it provides profiles of the systems that are consistent with our extensive fieldwork at semiconductor companies in Japan and the U.S.

[2] We also used a matched sample of the engineers from the two countries to document the HR and Knowledge systems. This subsample presented basically the same profile as the entire sample.

In the tables presented below, significant differences in the sample distributions between the two countries are reported using Analysis of Variance, where the Prob > F gives the level of significance that the countries differ in terms of the variable in question. For example, if a Prob > F is equal to 0.0013, then there is a significant difference at the 1 percent level between the two countries. Differences in the sample distributions that are statistically significant will be denoted as ** for p<0.01, * for p<0.05, and + for p<0.10.

The Engineers

The Japanese engineers in the sample are six years younger (born on average in 1958) and have more education (two years post BS) on average than the U.S. engineers (born on average in 1952 and 0.4 years post BS).** The U.S. engineers were more mobile than the Japanese engineers*: the U.S. engineers had worked for 1.6 semiconductor companies and spent 87% of their career at their current employer compared to the Japanese engineers, who had worked only for their current employer.

HR System

Work Organization.

Almost all (93%) Japanese engineers reported working a majority of their time in teams, compared to 42% of U.S. engineers (see Table 1). When we asked how the teams functioned (i.e., members worked independently, sequentially, reciprocally, or as a team), the Japanese members were slightly less likely to work independently or sequentially than the U.S. members. However when we combine the information on how independently the engineers worked, the U.S. engineers worked independently 81% of the time, compared to about 46% of the time for the Japanese engineers.

When asked about their major work activities, Japanese engineers spent the majority (52%) of their time in development work**, little time (15%) in administrative work**, and almost no time talking to equipment vendors (3%)**, material suppliers (2%)**, and customers (1%)**. U.S. engineers spent about the same amount of their time in development (23%) and administrative (27%) activities, and spent some time communicating with equipment vendors (5%), material suppliers (8%), and customers (6%).

Table 1. Time spent working in a team and independently

Country	A. Work majority of time on team**	B. % team time spend working independently + or sequentially*	C. % total time spent working independently**[a]
Japan	0.93	0.42	0.46
U.S.	0.42	0.54	0.81

a. Column C = (1-Column A) + (Column A)(Column B), which assumes the engineers either work 100% time ("majority") or 0% time ("not a majority") on a team.

Skill Development.

The engineers spent a substantial portion of their time in training—approximately one-fourth of their time. However the training for U.S. engineers was evenly split between classroom and on-the-job training, while the Japanese engineers received three-fourths of their training on the job. Over 85% of U.S. engineers had *classroom* training in problem-solving methods, communication skills, and leadership skills, and over 90% reported using this training in their work (Table 2). U.S. engineers were even more likely than their Japanese counterparts (93% vs. 63%) to receive company-specific classroom training. At least one-half of Japanese engineers had on-the-job training in design of experiments, problem solving methods, communication skills, and writing skills, and they were most likely to use their training in writing. (xx unclear)

Even with relatively high labor mobility, U.S. firms trained their engineers in basic knowledge as well as job-related nontechnical skills, and provided training that would be used regularly on the job. These results indicate that the Japanese companies were relying on the formal education of their engineers, who had more graduate training than their U.S. counterparts.

Pay and Promotion.

In our sample, compensation systems were more oriented to company performance in the U.S. than in Japan, and individual performance was rewarded in both countries. Profit sharing was reported by 82% of the U.S. engineers and none of the Japanese engineers**. None of the Japanese engineers reported receiving stock options versus one-third of the U.S. engineers**, where the options were worth 20% of total pay on average. Individual performance pay (reported by 46% of U.S. and 43% of Japanese engineers) was more common than knowledge-based pay (reported by 38% of U.S. and 18% of Japanese engineers).

Because of the importance of seniority, the compensation system for the Japanese engineers was more internal than the system for the U.S. engineers. "Creativity and initiative in problem solving" was ranked the number one criterion for pay and promotion in the U.S. and Japan. Seniority was the number two criterion for determining pay and promotion in Japan, while seniority was not ranked as an important criterion for promotion or pay by U.S. engineers*.

Most Japanese engineers only ranked a few criteria—for example, problem solving (#1) and seniority (#2)—as important for pay and promotion. The U.S. engineers ranked more criteria as important in promotion and pay decisions. "Suggestions and improvements made" was an important criterion (#2) for promotion** in the U.S., followed by "meeting production targets"*, "skills learned" **, "communication with people outside team but within company"** and "team participation"**. These five criteria were also reported as the most important for determining pay in the U.S., but only team participation and communications were ranked significantly different in the U.S. and Japan.

Other criteria for promotion and pay were significantly different across the two samples, although these criteria were not ranked by a majority of engineers in either country. U.S. engineers were more likely to rank "willingness to share knowledge with others"** as a criterion for pay and promotion and to rank "developing contacts with technologists in other companies"* as a criteria for pay. Japanese engineers were more likely to rank "presented papers at professional conferences"** and "publishes papers in professional journals"* as criteria for promotion.

Table 2. Training by Current Employer

	Type of Training[a]	Japan			United State		
		OJT	Class	Used?	OJT	Class	Used?
Technical	Problem-Solving Methods	0.54	0.49**	0.51**	0.52	0.85**	0.93**
	Design of Experiments	0.51+	0.37**	0.37**	0.30+	0.78**	0.67**
	Science	0.34	0.56	0.37	0.26	0.46	0.56
Non-Technical	Paper Writing	0.68**	0.53+	0.71**	0.20**	0.43+	0.43**
	Communication Skills	0.49	0.49**	0.43**	0.33	0.89**	0.93**
	Company Orientation	0.43	0.63**	0.43	0.41	0.93**	0.63
	Leadership Skills	0.37	0.49**	0.46**	0.37	0.93**	0.93**
% Total time spent in training (previous year)		20%*	6%**	--	12%*	12%**	--

***p<0.01, *p<0.05, +p<0.10

a. Proportion reporting that they received training by topic and where the training occurred on the job (OJT) or classroom (Class), and that they regularly used the training in their work (Used?).

Knowledge Systems

Next we profile the sources of knowledge and communication networks used by the engineers.

The large majority of engineers reported that teams kept an archive of documents from previous projects (86% of Japanese, 67% of U.S.)+. Only slightly fewer reported that the company has a document control system that stores information about previous projects (74% of Japanese, 63% of U.S.). However only one-third of the Japanese engineers received training on how to control confidential information compared to three-fourths of the U.S. engineers**.

Sources of Technical Information.

Engineers in both countries rated their colleagues within the company as their most important source of technical information, with journals and conference presentations as the second and third most important sources, respectively (see Table 3). The Japanese engineers rated journals, conference presentations, and patents as significantly more important sources of technical information than the U.S. engineers did. This indicates a greater reliance by the Japanese engineers on external public knowledge, which is consistent with the popular notion that U.S. companies are further along the technology curve. The U.S. engineers rated two private external sources—material suppliers and benchmarking studies—as significantly more important sources than the Japanese engineers did. However other private external sources— technologists at other companies, equipment vendors, and customers—were not ranked significantly different in the two countries.

Table 3. Importance of Sources of Technical Information
(based on 7-point scale from 1=not important to 7=very important)

	Japan	U.S.
Colleagues in own company	5.9	5.9
Journals, books, etc.**	5.6	4.5
Presentation at conferences**	5.1	4.3
Patents**	4.6	2.0
Technologists at other companies	4.1	3.6
Equipment vendors	4.0	4.4
Materials suppliers+	3.5	4.5
Customers	3.2	4.0
Benchmarking studies*	3.0	4.1

**p<0.01, *p<0.05, + p<0.10

External and Internal Communication Networks.

Within their own fabs, engineers from both countries rated face-to-face meetings with individuals as the most important channel, and group meetings or seminars as the second most important channel for finding out useful technical information. U.S. engineers were more likely than Japanese engineers to rely upon email* and electronic memos** and less likely to depend upon internal newsletters*.

At another fab within their company, face-to-face meetings were also the most important way to find out technical information for Japanese engineers, while email+ was the most important channel for U.S. engineers. Telephone contact was more important than group meetings in both countries. U.S. engineers were again more likely than Japanese engineers to rely upon electronic memos** and less likely to use company newsletters*.

Channels of communication with fabs *outside* one's company indicate that U.S. engineers operate in a knowledge system more oriented toward external private channels, and Japanese engineers operate in a knowledge system more oriented toward external public channels (see Table 4). The top channels of information about other companies for Japanese engineers were conferences, the popular press*, and public newsletters**. In contrast, the top channels of information for U.S. engineers were membership in a consortium**, trade journals, attending conferences, and personal telephone contacts*. Together these information channels indicate U.S. engineers have private access to information about leading technology outside their companies, while Japanese engineers rely on public sources for technical information.

Table 4. Channels of Technical Information Acquisition from Other Semiconductor Companies
(based on 7-point scale from 1=not important to 7=very important)

Access	Method	Japan	United States
External: Public			
	Attending conferences	5.1	4.8
	Popular press*	4.8	3.8
	Trade journals	4.6	5.1
	Public newsletters**	4.5	3.3
External: Private			
	Face to face meetings	3.6	4.3
	Visiting other fabs	3.4	3.7
	Personal telephone contact*	3.0	4.3
	Personal email	3.0	3.7
Company-directed			
	Reviewing patents**	4.3	2.0
	Reverse engineering*	2.9	1.9
	Consortium Membership**	2.5	5.3

**p<0.01, *p<0.05, +p<0.10

Two-thirds of engineers in both countries reported attending at least one conference during the year. For those attending conferences, the Japanese engineers attended 2.4 and U.S. engineers attended 1.7 (not significantly different). Most U.S. and Japanese engineers (73% and 69%, respectively) belonged to a professional society.

In learning information from equipment vendors, engineers in both countries rated face-to-face meetings as the most important source. This is not surprising, since equipment engineers from the vendor company are usually stationed at the fab.

Otherwise U.S. engineers relied more on private channels (telephone calls**, visit vendor's facilities, and email**), and Japanese engineers relied more on trade shows, the popular press**, conferences, and public newsletters**.

Problem-Solving Process.

To understand how the knowledge system influences how engineers do their jobs, we surveyed the chronology of knowledge acquisition activities in solving a specific technical problem that the engineer had worked on recently. We asked the respondents to describe the problem, classify it, and walk through the problem-solving procedures in chronological order (1 = the first source consulted, so a low score reflects earlier consultation). In both countries, the engineers approached a co-worker on the team, the whole team, or a co-worker on another team early in the process of problem solving (see Table 5). U.S. engineers were likely to approach someone from outside the company earlier in the knowledge-gathering process**, and Japanese engineers tended to go to their supervisors earlier in the process*. Although use of team and company documents was not ranked highly by most engineers, the U.S. engineers ranked use of these documents even lower than the Japanese engineers+.

Table 5: Sources of Knowledge to Solve a Specific Technical Problem
(ranked by importance)

Rank	Japan	U.S.
1	Whole team (3.7)+	Co-worker on team (4.2)
2	Co-worker on team (3.8)+	Whole team (5.7)+
3	Supervisor (6.3)*	Worker on another team (6.9)
4	Worker on another team (6.4)	Person outside company (7.2)**
5	Person from manufacturing (6.8)	Person from manufacturing (8.0)

**p<0.01, *p<0.05, +p<0.10

Summary: External or Internal Orientation Profiles

Our survey of engineers presents profiles of HR and Knowledge Management Systems that are strikingly similar in Japan and the United States in their internal orientation in some key components: spending substantial time in training, using company colleagues as the primary source of technical information, and relying on co-workers and teams for solving problems. They are also similar in their external orientation in the use of problem-solving performance in determining pay and promotion and the reliance on journals and conferences to learn about technical information at other semiconductor companies, However significant differences also exist. In work organization, U.S. engineers spent the majority of their time (81%) working independently, while their Japanese counterparts spent over half (54%) of their time working with others. Although U.S. engineers displayed more mobility than the Japanese engineers, the U.S. engineers received more classroom training. They were also more likely to use their training regularly on the job, which indicates their training was targeted to skills needed for their current job assignment. In skill acquisition, the U.S. companies seemed to be developing their workforce rather than relying solely on external hires. Seniority was not an important criterion in pay and promotion for the U.S. engineers, while seniority figured heavily for the Japanese engineers. Most U.S. engineers (82%) received profit sharing, while none of the Japanese engineers did.

For technical information, Japanese engineers were more likely than U.S. engineers to rely upon external public sources (journals, conference presentations, and patents); U.S. engineers were more likely to rely on external private sources (material suppliers and benchmarking studies). For technical information on other semiconductor companies, U.S. engineers were more likely than Japanese engineers to rely on external private contacts (consortium membership and personal telephone calls), while Japanese engineers were more likely to rely on external public sources (popular press, public newsletters, and patents).[3] When solving problems, U.S. engineers approached someone outside the company sooner in the process, and Japanese engineers went to their supervisor sooner.

Overall the survey results indicate that the engineers at these two leading U.S. semiconductor companies, compared to their Japanese counterparts at three leading Japanese companies, operate in more externally-oriented HR and Knowledge Management Systems and therefore have better access to knowledge about leading technologies outside their companies. We conclude that the use of Open Innovation Systems by the U.S. companies most likely provides them a competitive advantage in developing new products.

[3] Our finding that Japanese engineers were not likely to consult people outside of their company differs from Irwin and Klenow's finding that Japanese memory chip producers do appear to learn from each other and from other countries (Irwin and Klenow 1994).

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Figure 1. The Drivers of Creative Performance