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R&D COOPERATION AMONG COMPETITORS: LESSONS FROM THE VLSI SEMICONDUCTOR RESEARCH PROJECT IN JAPAN

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ABSTRACT

Today, it is clear that there is a need for cooperative R&D projects among competing firms. It is also clear that carrying out such projects successfully is very difficult. In this paper I explore the reasons why cooperation among competitors was successfully executed in the instance of the Japanese Very Large Scale Integrated Semiconductor Research Project.

Via study of both written materials and interviews with key participants, I find that high levels of funding, a clear target and a favorable technological climate all facilitated the project. However, the two basic reasons for success were: (1) selection of research projects of such a nature that "cooperation among rivals" clearly paid for participating firms and, (2) techniques used by project administrators to select and manage team members. I propose that the methods discussed here can be generally useful for the management of successful cooperative research among rivals.

1.0: Introduction

Today, many countries and companies recognize the at least occasional need for normally competing companies to engage in cooperative research projects.[1] At the same time, experience has amply shown that it is difficult for competitors to engage in successful cooperative efforts.[2] For this reason, I feel that it is worthwhile to review the history of the successful Very Large Scale Integrated (VLSI) Technology Research Project carried out in Japan from 1976 to 1980.

The Japanese VLSI Project successfully developed important process technologies to be used in making VLSI circuits in Japan. Unlike the other 40 or so research associations supported by the Ministry of International Trade and Industry (MITI), the VLSI Technology Research Association established a cooperative laboratory where much of the key research was done. Importantly for our present purposes, the corporate participants in this laboratory were all intensely competitive semiconductor manufacturing companies: Fujitsu, Hitachi, Mitsubishi Electric, Nippon Electric Co. (NEC), and Toshiba. The focus of this paper will be a detailed exploration of the means used to induce these fierce competitors to engage in this temporary and successful cooperation.

This paper first sketches the history and background of the project, next notes its achievements, and then analyzes the reasons for its success. The analysis is based on interviews with key participants in the projects and internal records made available by the VLSI Project as well as readily available materials such as company records, government publications, and published articles.[3]

2.0: A Brief Project History

Enhancing the competitive strength of the Japanese computer industry, especially in light of the competitive power of IBM, had long been an objective of the Japanese government. In 1971, in order to counter the introduction of the IBM's 370 series of mainframe computers, MITI forced reorganization of six Japanese computer makers into three paired groups: Hitachi-Fujitsu, Nippon Electric-Toshiba, and Mitsubishi Electric-Oki Electric. This effort was not a great success, however. Competition among these three pairs remained strong. In fact, even between "partners" there was considerable conflict, especially between Hitachi and Fujitsu. Despite the request of MITI, they did not cooperate closely within the groups either in production or in sales. Ultimately, the six firms remained largely independent.

In 1975, IBM was rumored to be planning a "future system," a new line of computers that would utilize VLSI. Commercial introduction was expected in 1978, or at the latest in 1980.[4] This great technical step forward was seen as a grave threat to the domestic industry. "We have too many computer makers in Japan to cope with the monster, IBM,"[5] said Tomisaburo Hashimoto, one of the powerful leaders of the ruling Liberal Democratic Party (LDP). "The reorganization of the computer industry and the establishment of a more unified and more integrated development organization for VLSI technology are urgently needed."[6]

Under LDP pressure, and despite grave misgivings by both computer companies and MITI, a program for VLSI technology development was started that had two main elements:

1. A reorganization of the existing three groups of computer firms into two groups: Fujitsu-Hitachi-Mitsubishi Electric group (group A) and Nippon Electric-Toshiba group (group B). (Oki Electric was in serious financial difficulty at the time, and was squeezed out.)

2. Establishment of a cooperative laboratory to enforce joint R&D effort by the five companies.

Although all five companies were unhappy with this new initiative, fearing loss of independence, they had to accept in order to obtain the substantial government R&D subsidies proposed under the scheme - and so they reluctantly agreed.[7]

The VLSI Technology Research Association began operations on March 10, 1976, as a four-year national project. Approximately 70 billion yen ($288 million)[8] was spent over the period, of which about 43 percent (30 billion yen) was in the form of interest-free loans from the Japanese government. Table 1 shows an outline of the Association.

-- Insert Table 1 around here --

The members of the Association were Fujitsu, Hitachi, Mitsubishi Electric, NEC, and Toshiba. They are all highly diversified companies producing not only semiconductors but also computers and other equipment. Figure 1 shows the organizational chart of the Association and the posts of involvement of the participating companies.

-- Insert Figure 1 around here --

The president of each participating company was appointed as a director of the Association. But the board of directors had little decision making involvement and met only two or three times each year. Below the board came the general committee whose members were vice presidents or managing directors of the five companies. It met every month, and made final decisions for the Association. Under the general committee were added two more specialized committees, the operational and the technical committees. They were composed of department managers of the participating companies and met the most frequently. The role of the operating committee was to cope with general, administrative problems. The role of technical committee was to select research topics, to staff research studies, and to allocate the required resources, including both financial and human resources.

The principle was established that the chairmanship of the Association's board should be filled alternately by company president of group A and then one of group B. However, the other key appointments were staffed by experts not affiliated with either group of competing firms. Thus, the managing director of the Association was a retired MITI bureaucrat, Masato Nebashi, who had much experience in managing national projects as an executive official. Also, the manager of cooperative laboratory was Yasuo Tarui, an engineer on loan from MITI's Electro-technical Laboratory, or ETL, which handles basic electronics research for the ministry.

He had an excellent reputation as one of the research pioneers in Japanese semiconductor technology.

Finally, a cooperative laboratory and two group laboratories were established. The cooperative laboratory (and office of the Association as well) was located in a wing of the central research laboratories of NEC (Kawasaki-shi, Kanagawa). Two group laboratories--Computer Development Lab, Ltd. (CDL) of the Fujitsu-Hitachi-Mitsubishi group (group A) and NEC-Toshiba Information Systems, Co. (NTIS) of the NEC-Toshiba group (group B), were scattered among the related companies.

3.0: Outcome

When the Japanese VLSI project started as a national project, there were substantial technological obstacles to be overcome to make VLSI microcircuits.[9] Not only were new microfabrication instruments and techniques required but an improved scientific understanding of the materials and processes was also needed. But the Association ultimately proved successful and the development of VLSI was achieved by the planned project expiration date of 1980. By this time, the four-year project had built three kinds of lithographies using electron beams, which can draw VLSI circuit components directly on a silicon wafer at high speed, achieving line widths of 1 micrometer or less. Moreover, a method of using computer-controlled electron beam systems had been developed; the influence of carbon and oxygen on silicon quality was made clear; and many other processing and testing technologies had been improved.[10] "Through this project," said Yasuo Tarui, the manager of cooperative laboratory, "the Japanese semiconductor technology caught up with IBM's technology. Especially in such narrow areas as an electron beam lithography, it seems to me, Japan moved into first place, past IBM."[11]

The significant research progress achieved can be seen in the patent record of the project: the total number of patent applications in the Association as a whole exceeded one thousand, of which about 50 percent were applications by the researchers of the cooperative laboratory.[12]

Also a second, very important indicator of success can be seen in the commercial results achieved by the approximately 50 machine builders such as Canon, Nikon, and Olympus Optical, who worked with laboratory researchers to develop semiconductor processing machines that would incorporate their advances. Machines commercialized by these firms reduced imports of foreign production equipment for semiconductor manufacture from 70 to 80 percent share of the domestic Japanese market in the first years of the VLSI program to about 50 percent in 1980 when the program concluded (Zysman et al., 1983, p.210). Japanese builders of semiconductor production equipment expanded their share of the world market from 10 percent in the 1970's to 35 percent in 1987 (Dertouzos et al., 1989, p.249). They strengthened the domestic Japanese infrastructure in semiconductor production and test capabilities and increased Japan's share of the world market for semiconductors.

4.0: Reasons for Success

What, then, accounts for the success of the project? I propose that a number of factors were important, and will elaborate on each below. I will begin by mentioning four important conditions favoring the project that were present at its initiation. Then, I will discuss the portfolio of projects that were studied cooperatively: It is my contention that cooperation by competitors clearly paid in the instance of these projects. Finally, I will discuss organizational means of enhancing cooperation among researchers drawn from competing firms and asked to work closely together in a cooperative laboratory.

4.1: Favorable Initial Conditions

The first of four initial conditions that I think was important to Project success is simply stated: the provisions of "enough" funding to induce cooperation. That is, the project funding was large enough to insure that each of the competing companies feared that if it did not join--and if competitors did--it might be left behind. "Enough" money to achieve this effect at that time was expenditure of an average of 17.5 billion yen ($72 million) during each of the four years of the project. This represented two or three times the potential annual R&D expenditure for semiconductors of the five major Japanese companies participating in the project. (However, expenditures of US firms was larger, as Table 2 shows. "This amount of money [spent by the VLSI Project] is not so much for R&D expenditure,"[13] commented Mark Shepherd, chairman and chief executive of Texas Instruments. "We can afford to bear, and do bear, such expenditure alone."[14] Also, Bell Laboratories was said then to commit 1,500 men and $117 million to the development of VLSI.[15]

-- Insert Table 2 around here --

The second important initial condition was that both the target and timing of the project were clear. Every participant knew the target was IBM's new line of computers utilizing VLSI, expected to be introduced in Japan in 1980 at the latest. This condition was favorable for the integration, motivation, and concentration of research efforts of the members.

Third, the five companies participating in the project had already accumulated the administrative know-how of joint R&D (e.g., patent management, budgetary request procedures, etc.) through their repeated experience of participating in national projects with subsidies from the government. With this experience, many administrative troubles could be avoided.

Fourth, the project was well-timed from a technological point of view. By the middle of the 1970's, the technology necessary for VLSI then was changing from the initiation stage in the innovation process to the evaluation and implementation stage.[16] Many key ideas, such as the use of X-ray or electron beam lithography in place of photo lithography had already been proposed and were ready for rapid development.

4.2: Proper Selection of Research Topics

As mentioned at the start of the paper, the VLSI Technology Research Association established a cooperative laboratory involving all five corporate participants at one site. Much of the most important work of the project was done at this site. In addition to the cooperative laboratory, two group laboratories were established. Each was staffed exclusively by personnel from the two competing groups of firms: Computer Development Lab, Ltd. (CDL) of Fujitsu-Hitachi-Mitsubishi group (group A) and NEC-Toshiba Information Systems, Co. (NTIS) of NEC-Toshiba group (group B).

One important way to get competitors to cooperate in research is to show them that it is in their interest. Von Hippel (1988) and Katz (1986) have shown that selection of projects is crucial in this regard: Cooperation among competitors can pay if projects are properly chosen. In essence, these authors have shown that cooperation will pay for projects for which a lack of exclusive control of findings does not cost a firm a critical competitive advantage. As we shall see, this principle was nicely adhered to by the designers of the research project agenda assigned to the VLSI cooperative laboratory, with the results that firms working on projects assigned to the lab felt that cooperation was in fact to their economic advantage.

The Association decided that the research themes of the cooperative laboratory would be limited to "common and basic technology," while the group laboratories would focus on "applied technology." Almost a year was spent in discussing and selecting research themes, including the discussions prior to the establishment of the Association. An informal working committee was organized, and face-to-face negotiations and discussions were carried on among the five companies. The industrial association of all five companies, Electronics Industries of Japan, acted as a mediator.

Because the companies had different interests, priorities, and expectations, there were many conflicts. But confrontation was allowed at all times, although this consumed much time. "They made no attempt to disguise their hostility; they discussed and discussed without disguising their selfish desires. That confrontation looked like a quarrel," said the managing director, Nebashi (Nebashi, 1980, p.60).

The "common technologies" ultimately selected were:

1. Development of the micro-fabrication methods which provide capability to handle sub-micron IC geometries (for example, electron beam and X-ray exposure methods);

2. Development of low-defect diameter silicon wafer substrata.

Basic Technologies selected were:

3. Development of practical processing methods using micro-fabrication equipment;

4. Development of evaluation and testing techniques for VLSI;

5. Definition of logic devices that can utilize the above results.

Applied technologies to be studied by the group labs rather than the cooperative lab included other topics under headings 3-5 and topics falling under one additional heading as well:

6. Development of improved computer-aided design technology.

Individual firms felt that it "paid" to do research projects selected as common or basic in a cooperative setting for one or two general reasons. First, in the instance of some projects selected, firms felt that R&D on the topic would improve their capability in an area that they saw as necessary - but at the same time felt that it was not as one of the most attractive areas for competing with rivals. For example, work to keep wafers flat during processing fell into this category. Second, projects were chosen that would in principle offer attractive competitive advantage to firms, but individual firms simply could not afford to do the project at all unless they did it cooperatively. In such instances, cooperative work did indeed rob them of the theoretical possibility of a competitive advantage over domestic rivals - an advantage they could not have afforded to obtain in any case. On the other hand, engaging in cooperative work offered the possibility of gaining a very real advantage as a group over rivals not in the group.

4.3: Management of the Cooperative Laboratory

Many Japanese strongly doubted that the five companies selected to participate in a cooperative research lab would in fact be able to work in close cooperation while simultaneously competing in the semiconductor market. This was especially a concern, given that the firms were dissatisfied with how the Association and the cooperative laboratory were established. They felt that they had been forced to organize the cooperative laboratory.

Nonetheless, successful cooperation of a substantial nature was achieved among researchers from different companies. As evidence, joint invention by researchers who were on loan from different companies was 16 percent of all patent applications filed (Tarui, 1980, pp.4-5). Success in this matter depended importantly on how the lab was managed.

High levels of communication and collaboration were created among researchers on loan from competing companies on a temporary basis by means of, first, the method of staffing of research teams, second, measures to actively promote communication and exchange of information and, third, the nature and actions of key project leaders.

4.3.1: Staffing

First and very importantly, it was not the five companies themselves but the manager of the cooperative laboratory, Tarui, who selected the approximately 100 researchers. Judging on the basis of previous performance, he compiled a list of names of experienced industrial scientists and engineers and then asked the five companies to lend them to the cooperative laboratory. He and the core researchers (about 20 people) had been personally acquainted with each other. By this means, companies were prevented from acting on their natural incentive to send their second-rate researchers to the cooperative lab. (Each firm would hope to benefit by this strategy by gaining contact with first-rate researchers of other companies while keeping its own best researchers at home.) Second, managers of the six research teams came from different companies (and in one instance from ETL, a government laboratory).

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First   --  Microfabrication technology (Hitachi)
Second  --  Microfabrication technology (Fujitsu)
Third   --  Microfabrication technology (Toshiba)
Fourth  --  Crystal technology (ETL)
Fifth   --  Processing technology (Mitsubishi)
Sixth   --  Testing and devices technology (NEC)
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(The names of the companies from which team leaders came are shown in parentheses.) All team leaders were technological specialists in their forties. They led and coordinated the daily research work. Under them there were no hierarchical level; instead, researchers of each team were divided into a few groups with different themes.

The principle of staffing adopted was that each team should not be composed solely of members from the same company. Therefore, under the team leader who was on loan from Toshiba (the third team), for example, we could find researchers not only from Toshiba but also from the other companies, although the majority of them were from Toshiba.[17]

4.3.2: Encouragement of Communication Across Teams

The significant impact of high levels of communication on the success of technological innovation within an R&D organization has been shown by Allen (1977). In the VLSI project various means were adopted to encourage communication and interaction between research teams in the actual innovation process.

First, and perhaps most important of all, research themes that overlapped the interests of all six teams were consciously included. For example, the problem of warping of silicon wafers involved not just the fourth team in charge of the crystal technology but also the other five teams.

Next, research results were shared regularly. An internal meeting was held once or twice every month during which current research results were reported and discussed. Usually about 40 researchers participated. Research results were also written down and published periodically in booklet form as the "Cooperative Laboratory Report," and this report circulated among the researchers. Furthermore, all research rooms were opened to all the teams every Saturday.

Many additional opportunities were used for face-to-face interaction among team members. Among these were scheduling, annual budget, staffing of the research teams, and purchasing plan of large-scale mechanical instruments. Moreover, because the Association was a national project, many documents were needed. For example, a detailed annual application for government subsidies had to be completed. In order to complete such documents, frequent face-to-face contact among participating researchers was necessary. Nebashi, managing director of the Association, asked researchers, not administrative staffs, to complete the documents by themselves. (At the same time, Nebashi arranged that evaluation of the researchers performance would remain with the employing firm. He did this to prevent the researchers from feeling isolated from their companies, thinking that such anxiety might be one of the most serious barriers to effective cooperation and interactions.)

Finally, many opportunities for off-the-job communication were also fostered. As is customary in Japan in building and maintaining relationships and communication, the researchers socialized regularly by drinking together after work, in this instance, at the executive office or the reception room of the Association. In addition, a number of voluntary extracurricular groups in sports and travel were organized by the researchers. In sum, through such intense and multiple communication and interaction, and fostered by the leadership (as discussed below), the cooperative laboratory gradually became a social unit, not a convenient conglomeration but a unified organization. As a result, problem-solving by groups rather than individuals began to be fruitful. This was a familiar and comfortable style for Japanese researchers.

4.3.3: Leadership

Finally, I propose that the nature and actions of two key project leaders, the manager of the cooperative laboratory, Yasuo Tarui, and the managing director of the Association, Masato Nebashi, were very important to the success of the VLSI Project. Both were experts not affiliated with either group of competing member firms, but they were leaders of different types.

Tarui was an experienced and highly respected engineer who was on loan from MITI's Electro-technical Laboratory (ETL). As noted earlier, he personally recruited the 20 or so core researchers, selected the remaining researchers on the basis of performance, and persuaded the participating companies to lend them to the cooperative laboratory for the project. By nature methodical and scrupulous, he focused almost completely on the technological affairs of the Association. He assumed the technological leadership in the organization. By contrast, the managing director, Nebashi, was a retired bureaucrat of MITI who had much experience in managing national projects as an executive official. He organized the various internal organizational arrangements in the Association, and undertook the external negotiations alone.

Nebashi made the division of authority clear (Nebashi, 1980, p.60).

> "On the research topics and the management of research, Tarui had full authority. Otherwise, nothing but failure will result. And so, I did not interfere in the research itself. My great interest in the organization was the human problem: how to coordinate the researchers from different companies and make them interact. I wanted them to become good friends, communicate to each other, and open their hearts.
>
> So, what I did was the typical Japanese way: All I did for this four years was to drink with them as frequently as I could. I wanted to understand their complaints on those occasions and tried to eliminate problem."

As an excellent troubleshooter and a generous, warm, and magnanimous man, he was well-liked by researchers and staff alike.

His efforts gradually paid off: The researchers, who were somewhat reserved with each other at first, became good friends and interacted well by the end of the project. When a farewell party was held in March 1980 at the completion of the project, everyone enjoyed it. Moreover, an alumni association was organized spontaneously and alumni newspapers were issued. No problems occurred when it came time to divide the production and test equipment owned by the Association among the five companies: The expensive equipment of various kinds was divided peacefully.

It should be pointed out that Nebashi's leadership was not simple "supportive-employee-centered leadership" or formal coordination and command. Through daily frequent contact, he always urged the researchers to realize the mission and value of the VLSI Project. He told them repeatedly that this project was unique in the world and that their laboratory would become the object of public attention; he told them what was distinctive about the aims and methods of the project; he really infused value beyond the technical requirements of the task at hand into the hearts of the researchers.[18] His efforts did much to help form the cooperative values of the group that contributed so much to Project success.

5.0. Summary

The case of the VLSI Technology Research Association has some practical implications for the development of Japanese technology. Late in the 1970's, Japan was in the midst of transition from borrowing technology to creating technology. The key concerns of many Japanese at the time were twofold: (1) how could innovative and leading technology be developed; and (2) what kind of R&D organizations should be provided on a national level in order to facilitate that process. The VLSI Technology Research Association started at this turning point and succeeded in effectively harnessing the development capabilities of normally competing firms in a collective effort. Some of national projects in Japan have been modeled after the organizational principle adopted in the VLSI Technology Research Association. In addition to its substantial technological impact, therefore, the VLSI project has served and continues to serve as an important model for the successful management of cooperative development projects in Japan.

Notes

1 An interesting analysis of joint R&D in the U.S. is given in Peck (1986). For a general discussion of the large-scale, multi-organizational research project, see Horwitch and Prahalad (1976), Horwitch (1979) and Horwitch (1980).

2 For a discussion of this topic, see Johnson (1973).

3 For a general description of the VLSI Project, see also Gresser (1980) and Okimoto et al. (1984).

4 See, for example, Nihon Keizai Shimbun, Tokyo, June 6, 1975 and September 17, 1975; Asahi Shimbun, Tokyo, July 16, 1975.

5 Nikkan Kogyo Shimbun, Tokyo, May 7, 1975 (translation by the author).

6 Ibid.

7 Asahi Shimbun, Tokyo, July 16, 1975.

8 The conversion rate of Y243 to the dollar is used.

9 See, for example, Robinson (1980).

10 For further particulars of research results, see Tarui (1980).

11 Nikkei Sangyo Shimbun, Tokyo, April 3, 1980.

12 Nihon Keizai Shimbun, Tokyo, April 7, 1980.

13 Citation from Semi, 1979, pp. 155-156.

14 Ibid.

15 Nikkei Sangyo Shimbun, Tokyo, January 1, 1976.

16 For a discussion of the stages in the innovation process, see for instance Zaltman et al. (1973).

17 For a more detailed discussion of this principle of staffing, see Tarui, 1980, p. 4.

18 The significant role of leaders in infusing value is pointed out very interestingly by Selznick (1957). On this topic, see also Jelinek (1979).

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Table 1 Outline of the VLSI Technology Research Association

Purpose	To develop the technology necessary for VLSI
Period	4 years beginning in fiscal 1976
Funds	70 billion yen ($288 million) including 30 billion yen from the government
Members	Five semiconductor-computer manufacturing companies: Fujitsu, Hitachi, Mitsubishi Electric, Nippon Electric Co. and Toshiba
Research items	Microfabrication technology, semiconductor crystal technology, design technology, processing technologies, testing technologies and development of actual devices
Laboratories	Two kinds of laboratories established: (1)Cooperative Laboratory to work on the common and basic technology (2)Two Group Laboratories to work on the applied technology: -Computer Development Laboratories (CDL) for the Fujitsu-Hitachi-Mitsubishi group -NEC-Toshiba Information Systems Laboratories (NTIS) for the NEC-Toshiba group
Managing director	Masato Nebashi, a retired MITI bureaucrat
Manager of the Cooperative Laboratory	Yasuo Tarui, an engineer on loan from MITI's Electro-technical Laboratory
Location of the laboratories, the office & Cooperative Laboratory	A wing of the central research, NEC

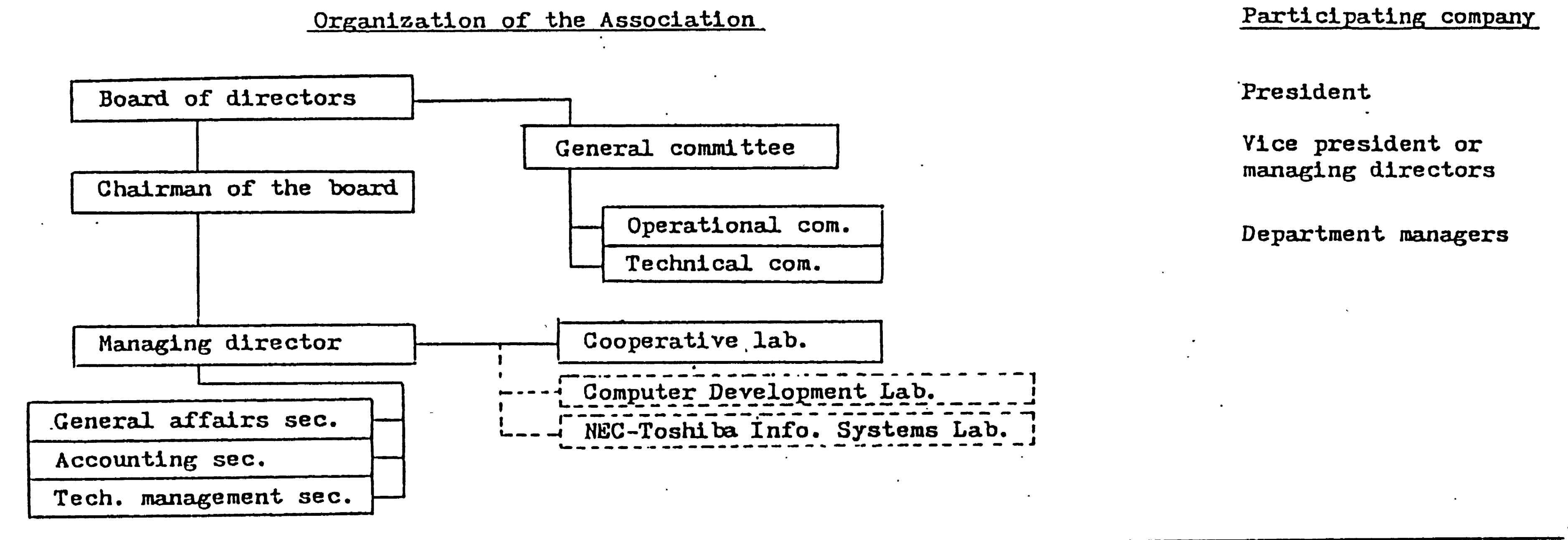
Note: Made by the author based on published materials.

Table 2 R & D Expenditures in U.S. Major Semiconductor Manufacturers

	R&D Expenditure ($ million)	
	1976	1977
Fairchild Camera & Instrument	44.0	43.6
Intel	20.7	27.9
Motorola	101.5	109.7
National Semiconductor	24.9	31.8
Texas Instruments	72.2	96.2

Source: Business Week, June 27, 1977, p.68 and July 3, 1978, p.76 and Annual Report of Intel Corporation for 1980.

Figure 1 Organizational Chart of VLSI Technology Research Association and the Posts of Involvement of the Participating Companies



Source: Internal materials of the Association.