

**Columbia-Yale Project: Use of Software to Achieve Competitive Advantage**

## **SEMICONDUCTORS: NEC**

### **Sustaining Long-term Advantage Through Information Technology**

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# 1 Introduction to the project<sup>1</sup>

This case study describes how the Japanese firm NEC uses software technology and information systems to achieve competitive advantage. It is part of a broader project entitled *Software as a Tool of Competitive Advantage*, which is supported by a three-year research grant from the Alfred P. Sloan Foundation. The project employs the case study method to examine and compare how U.S. and Japanese firms who are recognized leaders in using software and information technology have organized and managed this process.<sup>2</sup> While each case is complete in itself, it is part of this larger study.<sup>3</sup>

This semiconductor industry case study together with other cases advance the hypothesis that leading software users in the U.S. and Japan are very sophisticated in the ways they integrate software into their management strategies. Their software strategy works to institutionalize organizational strengths, capturing tacit knowledge on an iterative basis.<sup>4</sup> In the past, Japanese firms' software strategy relied heavily on customized and semi-customized software (Rapp, 1995b). However, this is changing towards a more selective use of package software managed via customized systems. In turn, U.S. firms who have often relied more on packaged software, are adapting more customized programs, especially for systems needed to integrate software

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<sup>1</sup> The co-principal investigator and I would like to thank the Sloan Semiconductor Industry Center at Berkeley for their invaluable assistance, Madeleine Sorapure, and the participants at the Association of Japanese Business Studies conference in Chicago for useful comments. They would like to thank especially Mr. Yoichi Numata, Vice President of NEC, Mr. Akihiko Morino, Chief Engineer of the Semiconductor Group of NEC, and Mr. Yoshitada Fujinami, Senior Manager of NEC for their time and insights. Any opinions, findings, or conclusions expressed in this paper are those of the author and do not necessarily reflect the views of NEC. Support from the Alfred P. Sloan Foundation is gratefully acknowledged.

<sup>2</sup> The industries and firms that are examined in this study are: food retailing (Ito-Yokado and H. Butts); semiconductors (NEC and AMD); pharmaceuticals (Takeda and Merck); retail banking (Sanwa and Citibank); investment banking (Nomura and Credit Suisse First Boston); life insurance (Meiji and USAA); autos (Toyota); steel (mini-mills and integrated mills, Nippon Steel, Tokyo Steel and Nucor); and apparel retailing (WalMart).

<sup>3</sup> Research on Advanced Micro Devices (AMD) as the counterpart case to NEC is underway.

packages into something more closely linked with their business strategies, markets, and organizational structure. Thus, coming from different directions, there appears some convergence in the approach these leading software users are adapting. Furthermore, the cases confirm the hypothesis that a coherent business strategy is a necessary condition for a successful information technology strategy (Wold and Shriver 1993).<sup>5</sup> These strategic links for NEC are presented in the following case.

This along with the other case studies also illustrates that the implementation and design of each company's software strategy depends in the competitive environment, industry and strategic objectives. These factors influence how firms choose between packaged and customized software options for achieving specific goals and how they measure their success. Indeed, as part of their strategic integration, the firms studied have linked their software strategies with their overall management goals through clear mission statements that explicitly note the importance of information technology to the success of the firm.

In addition, NEC has introduced an active CIO (Chief Information Officer) and IT (information technology) support group participation in the decision making structure making the totally independent MIS department a thing of the past. This may be one reason why outsourcing has not been a real option for them, even though their successful business performance is not based solely on software. Rather, as shall be described below, software is an integral element of their overall management strategy and plays a key role in serving corporate goals such as enhancing productivity, improving inventory management or strengthening customer relations.

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<sup>4</sup> Summary results for the completed cases can be found in William V. Rapp, "Gaining and Sustaining Long-term Advantage Through Information Technology: The Emergence of Controlled Production," Working Paper, Center on Japanese Economy and Business, Columbia University, December 1998.

<sup>5</sup> Ibid.

In NEC's case information systems complement and integrate the firm's manufacturing, R&D, and marketing approaches, reflecting the company's clear understanding of their business, their industry and the firm's competitive strengths. This clear business vision has enabled NEC to select, develop and use the software they require for each business function. Since this vision impacts other corporate decisions, they have good human resource and financial characteristics too.

A common theme that NEC shares with other leading software users is the creation of large proprietary interactive databases. These databases promote automatic feedback between various stages and/or players in the production, delivery and consumption process. Also common to other leading software users is NEC's ability to use IT to reduce inventories and improve control of the production process. This is done by building beneficial feedback cycles or loops that increase productivity in areas as different as R&D, design, production, test and marketing, while reducing cycle times and defects by integrating production and delivery. Reduced cycle times decreases costs and increases the reliability of forecasts due to the shorter time period. Customer satisfaction and lower inventories are improved through better on-time delivery. Thus, information systems is a critical factor in the leading software users' overall business strategies, with strong positive implications for doing it successfully, and potentially negative implications for competitors.

One important consideration in this respect is the possible emergence of a new strategic manufacturing paradigm, "controlled production," in which NEC appears to be a leading participant. In the same way mass production dramatically improved on craft production through the economies of large scale, plants that produced and used standardized parts and lean production improved on mass production due to a continuous manufacturing line, reduced

inventories and better demand forecasts. What we call “controlled production” seems to significantly improve productivity through monitoring, controlling and linking every aspect of manufacturing and distribution of a product or service, including after-sales service and repair.

Such controlled production is only possible by actively using information technology and software systems, to continuously monitor and supervise functions that had previously formed a rather automatic system response to changes in demand. This may be why industry analysts consider information technology that is integrated operationally and organizationally as an important factor to business success. Therefore, at NEC the software and systems development people are part of the decision making structure within the semiconductor division, while the system itself is an integral part of the way they organize, deliver, and support the semiconductor business, from R&D to sales forecasting and market intelligence. This sequence is particularly critical in the integrated circuits market, where there are large and rapid swings in the demand and supply for particular products.

Therefore, Seagate Technology may be correct for NEC too when they state in their 1997

*Annual Report:*

We are experiencing a new industrial revolution, one more powerful than any before it. In this emerging digital world of the Third Millennium, the new currency will be information. How we harness it will mean the difference between success and failure, between having competitive advantage and being an also-ran.

In NEC’s case, as with the other leading software users examined, the key to using software successfully is to develop a mix of packaged and customized software that supports their business strategies and differentiates them from competitors. However, with the exception of using English as their common language within the division, they have not tried to adapt their organizational structure to the software used. Furthermore, they perceive that functional and

market gains have justified the additional expense incurred in customizing certain systems, including the related costs of integrating customized and packaged software into a single information system for the division. They do this by assessing the possible business uses of software organizationally and operationally, and especially its role in enhancing their core competencies or particular functions. While NEC will employ systems used by competitors if there is no business advantage to developing their own, they reject the view that information systems are generic products best developed by outside vendors, who can achieve low cost through economies of scale and investments in the latest technology.<sup>6</sup>

In undertaking this and the other case studies, the project team sought to answer certain key questions while still recognizing firm, country and industry differences. These have been explained in the summary paper *Gaining and Sustaining Long-term Advantage Through Information Technology: The Emergence of Controlled Production*, a Center on Japanese Economy and Business working paper by William V. Rapp. An outline of the questions can be

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<sup>6</sup> NEC and the other cases have been developed using a common methodology that examines cross-national pairs of firms in key industries. In principle, each pair of case studies focuses on a Japanese and American firm in an industry where software is a significant and successful input into competitive performance. The firms examined are recognized by the Sloan Industry Centers and considered within their industry as ones using software successfully. To develop the studies, we combined existing research results with questionnaires and direct interviews. Further, to relate these materials to previous work as well as the expertise located in each Industry Center, we held working meetings with each Center and coupled new questionnaires with the materials used in the previous study to either update or obtain a questionnaire similar to the one used in the 1993-95 research (Rapp 1995b). This method enabled us to relate each candidate and industry to earlier results. We also worked with the Centers to develop a set of questions that specifically relate to a firm's business strategy and software's role within that. Some questions address issues that appear relatively general across industries such as inventory control. Others such as managing the IC manufacturing process are more specific to a particular industry. The focus has been to establish the firm's perception of its industry and its competitive position as well as its advantage in developing and using a software strategy. The team also contacted customers, competitors, and industry analysts to determine whether competitive benefits or impacts perceived by the firm were recognized outside the organization. These sources provided additional data on measures of competitiveness as well as industry strategies and structure. The case studies are thus based on extensive interviews by the project team on software's use and integration into management strategies to improve competitiveness in specific industries, augmenting existing data on industry dynamics, firm organizational structure and management strategy collected from the Sloan industry enters. In addition, we gathered data from outside sources and firms or organizations with which we worked in the earlier project. Finally, the US and Japanese companies in each industry were selected on the basis of being perceived as successfully using software in a key role in their competitive strategies. In fact, these companies perceive their use of software in exactly the same manner. The competitive benefits were generally confirmed after further research.

found in Appendix B, where NEC's profile is presented based on our interviews and other research. Readers who wish to assess for themselves the way NEC's strategies and approaches to using information technology address these issues may wish to review this prior to reading the case. For others it may be a useful summary.<sup>7</sup>

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<sup>7</sup> The questions are distinguished into the following categories: General Management and Corporate Strategy, Industry Related Issues, Competition, Country Related Issues, IT Strategy, IT Operations, Human Resources and Organization, Various Metrics such as Inventory Control, Cycle Times and Cost Reduction, and finally some Conclusions and Results. They cover a range of issues from direct use of software to achieve competitive advantage, to corporate strategy, to criteria for selecting software, to industry economics, to measures of success, to organizational integration, to beneficial loops, to training and institutional dynamics, and finally to inter-industry comparisons.

## 2 Introduction to the case study

The invention of the transistor in the late 1940s and the subsequent design of the integrated circuit revolutionized the storage and processing of information, affecting all aspects of economic activity. While mature industries, such as the vacuum tube seemed to disappear, new industries emerged including the semiconductor, computer, and software industries. The latter was established from efforts to organize, design, and produce programs that could maintain and process information. Even though software has been a critical factor in production processes, precisely how firms design and implement their software strategies, measure their performance, and choose among different software options is less clear. Nor is it readily apparent how firms integrate these strategies with their management objectives. This study attempts to better understand these issues by addressing the role and impact of software as a tool to create competitive advantage in the semiconductor industry.

One important outcome of an earlier study (Rapp, 1995b) was that U.S. software users rely more on less expensive packaged software, whereas Japanese consumers tend to use more customized or semi-customized software. The above study finds that approximately 85% of the large organizations' software expenditures in Japan are for customized software. In terms of designing and producing advanced, customized, or packaged software, however, the Japanese industry is not as developed. Thus, the reliance on customized software is costly not only for the software-users, but for the Japanese developers and producers of software as well.

This result questions the rationality of the Japanese firms, since an outcome involving customized or semi-customized software seems not to be cost minimizing. Researchers argued that this (seemingly) non-rational strategy resulted in technologically backward information

systems, inefficient management, and a fragmented Japanese software industry. Conversely, others argued that if software is used to capture organizational strength and tacit knowledge, the customized software strategy may be rational and economically efficient (Rapp, 1995a). The present case study attempts to address this issue by closely examining the semiconductor division of NEC, a market characterized by global competition, dynamic economies of scale, and rapid technological change.

The case begins by placing the Japanese semiconductor industry in global context and examining the governmental policies and subsequent growth of the domestic and international semiconductor markets. As Japan's leading semiconductor producer, NEC's evolution and current business strategies are an integral part of this development. At the same time, the study of NEC's organizational structure and product choice allows an understanding of the company's use of and demand for software. The case study concludes by examining the use of information technology as a tool to create competitive advantage. The last section summarizes the findings.

However, to appreciate the role of information technology within NEC's Semiconductor Group, some important characteristics of the market have to be outlined.

### **3 Semiconductor industry: an overview**

The semiconductor industry is considered the vehicle of the “information revolution” or “second industrial revolution.” Observers have labeled it “strategic” for two reasons: the importance of semiconductors as an intermediate good for high technology products; and the empirically-documented presence of dynamic economies of scale through learning-by-doing and knowledge spillovers.

This section provides an overview of the semiconductor products and the manufacturing process. The latter, one of the most complex production processes in industrial history, determines some important economic characteristics. Historically, descriptions of substances with properties similar to today's semiconductor materials have existed since the early nineteenth century. However, the understanding and utilization of their technological importance is a mid-twentieth century phenomenon (Braun and Macdonald, 1982, chapter 2; Morris, 1990, chapter 3).

### **3.1 Product Description**

Semiconductor materials are active electronic elements that can be either conductors or insulators (non-conductors).<sup>8</sup> In a conductor, the structure of the electrons facilitates the flow of electricity, while in an insulator it impedes the flow of electricity. At low temperature semiconductors are poor conductors but the degree of their conductivity changes depending on temperature, impurity, and optical excitation.

#### **3.1.1 Classification**

Semiconductors can be classified by the material, power capability, function, design, and technology employed. Yet another classification is based on the product type, resulting in two main categories: discrete devices, and integrated circuits (ICs).<sup>9</sup> Discrete devices consist of

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<sup>8</sup> Electronic components are usually classified as active and passive. Active components such as semiconductors modify an electronic signal, and perform the amplification, modulation, generation, and switching operations. Passive components such as capacitors, resistors, inductors, and relays, store or impede the flow of electricity. See Meindl (1977).

<sup>9</sup> Note that this general classification is by no means universally accepted. For instance, the International Trade Commission introduces hybrid devices as a third category. Hybrids are special packaging compositions of single or multiple integrated circuits with discrete components. In 1990 hybrids represented 6.3% of the world semiconductor market (USITC, 1993, p. 1). Alternatively, the OECD introduces optoelectronics as a third category. Optoelectronics are devices that emit or respond to light. In 1988 optoelectronics represented about 4% of the world semiconductor market (OECD, 1992, p. 135).

transistors, diodes, and special devices. They are single components of electrical circuitry, which perform the rectification (diodes), amplification (transistors), and switching (transistors) functions. Conversely, integrated circuits incorporate active and passive elements on a single semiconductor substrate.

Increases in the number of components that an integrated circuit incorporates reflect technical progress for the industry. In the mid-1960s, Gordon Moore, then at Fairchild, noticed that the number of components per circuit had been doubling every year and predicted that this trend would continue. This observation came to be known as Moore's Law, and holds even today with a slight modification: transistors on a circuit double every eighteen months (Noyce, 1977, p. 65; Hutcheson and Hutcheson, 1996, p. 54). Generally, devices containing up to 100,000 components are considered very-large-scale-integration (VLSI) while those containing more than a million components are considered ultra-large-scale-integration (ULSI).<sup>10</sup> Recently this amazing evolution of integrated circuit technology has resulted in chips that contain a whole system, the "system-on-silicon." Integrated Circuit Engineering estimates that since 1970 the integration capabilities have increased by 35% to 50% per year (ICE, 1993, p. 5-26).

ICs are further divided into linear, or analog and digital. Linear or analog ICs are used to process electronic signals in an analog mode. They are considered mature products and they are used extensively in television and radio equipment. Digital ICs, in contrast, are used to process electronic signals in a digital fashion. They operate as on/off switches that, depending on the input, store and process information by utilizing a binary system. They are used in virtually all the microelectronics industry, from aerospace technology to consumer electronic equipment. Of

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<sup>10</sup> Devices containing up to 100 components are considered small-scale-integration (SSI), while those involving 100 to 1,000 components are considered medium-scale-integration (MSI). By the early 1970s the industry had moved to large-scale-integration (LSI) where ICs included 1,000 to 100,000 components. See Veendrick (1992), figure 0.1,

a total \$63 billion worldwide semiconductor market in 1990, the market for analog ICs was \$11 billion, while for digital ICs it was \$37 billion (USITC, 1993, Figure 2, p. 3).

Digital ICs are further divided into logic devices, memory devices, and microprocessors. Logic devices perform logical operations on data, and memory devices store and retrieve information. Finally, microprocessors combine the functions of the logic and memory devices and perform the operation of the central processing unit (CPU) of a computer.

The largest part of the semiconductor market is memory devices, or simply memories. In 1990, they accounted for an estimated 28% of the IC market and 20% of the total semiconductor market; these figures represented an estimated market value of \$13 billion (USITC 1993, Figure 2, p. 3). Historically the Japanese semiconductor industry focused on producing memories. Given their importance to the case, the following is a brief outline of their characteristics.

### 3.1.2 Memory devices

Memories are measured in binary units (bits) of information stored and are characterized by their storage capacity, reliability, and cost per bit.<sup>11</sup> In addition, some time-related dimensions are very important, such as access time (i.e., speed of operation), cycle time, and data transfer time.

Memories are classified as volatile, where all the information stored is lost in the absence of power, and non-volatile, where information stored is retained even in the absence of power. Another way to categorize memories is based on their ability to store (“write”) and retrieve (“read”), resulting in three groups: read-only memory, serial memory, and random-access memory.

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and Gruber (1994), p. 145. For a different classification range see Braun and Macdonald (1982), p. 103, Levin (1982), p. 45, OECD (1985), p. 9, and Howell et al. (1988), p. 26.

<sup>11</sup> For an outline of the types and characteristics of memories see Hodges (1977), and Veendrick (1992), chapter 7.

Read-only-memories (ROM) contain data that cannot be altered. This type of non-volatile memory can be found in pocket calculators. To alter the information, one needs to replace the storage capacitor of the device. Other non-volatile memory types are the programmable-read-only-memory (PROM) that is used in the computer keyboard, the erasable-PROM (EPROM) and the electrically erasable PROM (EEPROM). In both EPROMs and EEPROMs the information stored can be deleted with ultraviolet light and electrical means respectively, and the devices can be reprogrammed.

Serial memory is a volatile type where the information is accessed in the same sequence it was stored. It is used mainly in video applications. Finally, random-access-memory (RAM) is a volatile type where the information stored can be altered. RAMs are used extensively in the computer industry. They can access any storage location at the same time, as opposed to serial-access or block-access memories. They are organized in rectangular arrays of rows and columns. An intersection of a row and column forms a cell in which one bit of information is stored. RAMs are divided into static (SRAM) and dynamic (DRAM). SRAMs are faster devices, that do not need constant application of electric current to maintain their content. By contrast, DRAMs erase all information stored if the power is turned off.

DRAM is the dominant memory product, accounting for 54% of the memory market in 1990. Worldwide consumption has increased from \$13 million in 1971 to an estimated \$7 billion in 1990.<sup>12</sup> The first commercially viable DRAM was the 1K, where K (kilo) represents 1,024 bits of information. Introduced in 1970, it was followed by a new generation approximately every three years with each new DRAM generation containing four times the capacity of its predecessor. Since 1970 the following generations have been introduced in the market: 1K, 4K, 16K, 64K, 256K, 1M, 4M, 16M, 64M, and 256M, where M (mega) stands for 1,024K bits of

information. Currently, devices with 1G, where G (giga) stands for 1,024M bits of information, are being tested.

The semiconductor industry considers DRAMs a “commodity” product. They are produced in great volume, with highly standardized features that allow the products of different manufacturers to be close substitutes. DRAMs might differ in design and performance by manufacturer, but all producers use the same speed classifications, package type, pins, and technical qualifications. Therefore, DRAMs with similar specifications can be substituted in a given use even when produced by different manufacturers.

### **3.2 Manufacturing**

The manufacturing of semiconductor devices is considered the most complex mass production procedure in the industrial history. It requires the coordination of highly skilled personnel trained in engineering, physics, chemistry, metallurgy, and so on. The process consists of creating and integrating microelectronic devices onto a wafer, a sliver of silicon cut from a single silicon crystal, which has been grown in laboratories. The wafer is a smooth silicon disk, highly polished on the one side with a diameter that has increased to eight inches nowadays, with plans to expand further. Depending on the device’s complexity and size and the wafer’s diameter, several hundred identical devices are contained in each silicon disk. These devices are also called dice or simply chips. Yet, due to the large number of components per chip, the number of chips per wafer has not risen despite the increase in the diameter of the wafer.

The manufacturing process has evolved in both scope and complexity during the last twenty years, especially in the areas of substrate material, the number of transistors employed, the minimum device size, the number of interconnections, and the materials used in the different

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<sup>12</sup> The 1971 data is from Finan and Amundsen (1986), p. 307. The 1990 data is from USITC (1993), Figure 2, p. 3

production stages.<sup>13</sup> A stylized representation of a device's manufacturing process distinguishes three stages: design, fabrication, and assembly and final testing (USITC 1993, p. 4).

### 3.2.1 Design

Because semiconductors have a complex three-dimensional structure, chip designers form a detailed pattern of the device's multilayer structure, the layout, by using computer-aided design (CAD) equipment. In this way, designers conceptualize new devices, select the processing stages, and determine the size and location of the circuits. Finally, the layout is subjected to a series of functional, electrical, and design-rule tests. This is the most costly and time-consuming stage of the semiconductor manufacturing. The layout for the most complicated designs, such as those for microprocessors, can take years to complete, while for the simpler static memories design the layout can be completed in few months (Oldham, 1977; Yoffie 1987).

### 3.2.2 Fabrication

The second stage of the production process involves several steps. Initially, a plate called a reticle or photomask, usually about ten times the final size of the device, depicts the completed layout of each layer. The image of the reticle is then reduced through a series of sophisticated lenses, and is projected through a mask onto a wafer. The wafer already has an insulating layer of silicon dioxide and has been coated by a photosensitive material, the photoresist. This process of tracing the circuit pattern onto a wafer is called masking, photolithography, or simply lithography, and is considered the foundation of microelectronic technology (Oldham, 1977, p. 123). The lithography equipment, or stepper, follows a “step and repeat” process in which once an area of a wafer has been exposed to the photolithography process, another area is positioned

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<sup>13</sup> See Oldham (1977), U.S. Department of Commerce (1979), Hazewindus and Tooker (1982), and Veendrick (1992).

under the beam electronically. This process depicts where impurities will be introduced and where the connecting wires will be placed.<sup>14</sup>

Next, a series of chemical baths washes the photoresist from the light-exposed parts of the silicon disk, thus transferring the circuit patterns onto the surface of the silicon disk. This is called etching. Once access to the silicon has been established, dopants are introduced either by diffusion or ion-implantation techniques to alter the electric properties of the substrate. Then insulating material is introduced through a deposition stage and metal connections are placed between transistors. Depending on the complexity of the device produced, these steps are repeated several times.

After coating the wafer with a passivation, a scratch-protective layer, the final fabrication stage consists of testing the wafer for defective chips. This probe-test involves highly sophisticated equipment and computer programs to measure the output response of a circuit to pre-determined stimuli. This completes the batch-manufacturing process.

### 3.2.3 Assembly and final testing

The wafer is then ready to be sawed or scribed to obtain individual chips. Dice that successfully responded to the probe tests are packaged. Each die is attached to a supporting frame, and is encapsulated into a plastic or ceramic package. A series of standardized quality and reliability tests concludes the manufacturing process.

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<sup>14</sup> Industry participants and experts question the capability of the advanced optical lithography employed today for the fabrication of the forthcoming gigabit-chip generation. See Oldham (1977), p. 123, and Veendrick (1992), p. 93-96. For an outline of the debate concerning optical and x-ray lithography, see Stix (1995). See also Hutcheson and Hutcheson (1996) for a discussion of the technological barriers in the fabrication process and the interaction between economics and technology in the semiconductor industry.

### 3.3 Economics of the industry

Several stylized facts that characterize the industry can be directly traced to the complex semiconductor manufacturing process.

#### 3.3.1 Demand side considerations

While the number of applications that require semiconductors is expanding rapidly, the computer industry remains the main end-user, absorbing more than 51% of the total merchant market and perhaps an even larger share of the captive market (See TABLE 1).

TABLE 1  
*Total merchant semiconductor market*

	1991	1991	1992	1992	1994	1994	1995	1995
	bil US\$	%						
Computer	23.2	40.8	29	43	50.9	48.6	75.5	51.1
Consumer	15.2	26.8	17	25	20.4	19.5	25.9	17.5
Communications	7.6	13.4	9.1	13	15.5	14.8	21.8	14.7
Industrial	6.3	11.2	7.5	11	11.3	10.8	15.3	10.4
Automotive	3.1	5.5	3.4	5	5.2	4.9	7.7	5.2
Military	1.3	2.3	2	3	1.4	1.3	1.5	1
Total Semiconductor Market	56.8	100	68	100	104.6	100	147.7	100

Sources: Adapted from ICE (1997), figure 1-10, p. 1-10, except for 1992 which is adapted from ICE (1993), figure 1-13, p. 1-10.

TABLE 2 below reveals the cyclical nature of the industry, a fact that many analysts have described in some detail. However, as devices become more specialized and the range of semiconductor applications increases, the cycles become more product specific. Thus the demand for semiconductors used in cellular telephones may be subject to different cycles than for those used in automobiles. A factor that makes the industry cycles more intense, is the

general practice of customers to place orders with more than one supplier in order to ensure prompt and sufficient delivery of semiconductors.

TABLE 2  
*Annual growth rates of worldwide semiconductor industry revenues, 1978-1992*

Year	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Annual growth rate	28.5	24.1	27.2	5.3	2.9	26.1	46.4	-16.8	23.9	23.7	38.6	7.3	1.6	8.1	9.6

Source: SIA 1993 Annual Databook, p.7

The immediate implication of the above is an increase in inventories, which are then subject to swings in demand due to both economic effects and technological obsolescence. Thus, corporate success in this industry is closely related to two factors: accurate forecasting of demand; and “flexible” manufacturing techniques that allow inventories to be managed.

### 3.3.2 Supply side considerations

Semiconductor manufacturers are generally divided into two groups, merchant and captive. A merchant producer serves the open market. It generally operates a large open-market sales force and well-organized open-market development programs.

Conversely, a captive producer is one that primarily or sometimes even exclusively serves an internal or “in house” market. ICE (1993, p. 3-1) defines captive as the producer that sells less than 25% of its production in the open market. Therefore, a captive producer does not need a considerable open-market sales force, or an open-market device development program. Interestingly, based on the Integrated Circuit Engineering definition, all captive firms are U.S. based, such as IBM, GM-Hughes, Hewlett-Packard, and DEC. Although European, Japanese, and Korean manufacturers transfer semiconductor devices internally, they sell more 25% in the

open market. ICE estimated that in 1992 approximately 22% of the North American IC output was captive (ICE, 1993, p. 3-2).

One reason foreign firms and smaller U.S. producers are not primarily captive is because semiconductor production costs are very sensitive to improved yields from “learning-by-doing,” and economies of scale. Thus, access to the global market is important in lowering costs.

A measure of great importance in the industry is the yield, that is, the percent of saleable chips out of the total number of chips produced. Because of the complexity of the manufacturing process, the yield for a new product is very low, sometimes less than 10%. The initial low yield may be due to problems with the wafer, the circuit design, or the fabrication process.<sup>15</sup> Through readjustment, fine-tuning, and learning, a yield of 90% can be realized for mature products. The ability to move quickly to this stage is a key component to business success for any semiconductor firm. Therefore, modeling IC yield is very important in predicting the cost and availability of a particular device. However, because the modeling is based on fundamental parameters of an established technological process, the yield of future ICs is usually underestimated. Nevertheless, yield modeling does not intend to predict the future; rather it aims at improving the process and design of present generations.<sup>16</sup>

Cost declines can also be studied by the learning-by-doing model that estimates the percentage that production costs decline for every doubling of cumulative volume produced. Several researchers have tested this hypothesis for aggregate as well as disaggregate series of

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<sup>15</sup> For a detailed analysis see Bertram (1983). See also Veendrick (1992), p. 124-128, ICE (1993), section 3, and Gruber (1994), appendix II.

<sup>16</sup> For a description of different yield models see Bertram (1983), and Gruber (1994), appendix II. Although there are a number of models in the literature, the most prevalent are the Poisson-, Murphy-, and Seed-yield models. Frequently, a model is used for a specific device; for instance, Murphy's model is employed to estimate the yield for memory devices. See ICE (1993), p. 3-14.

semiconductor products, resulting in a range of outcomes.<sup>17</sup> Still, given the complex production process outlined above many firms concentrate their efforts on increasing yields in the manufacturing of high-volume, standard products with simple design. The underlying reasoning is twofold: first, when producing such chips it is easier to ascertain whether low yields are due to a fault in the design or in fabrication; second, the skills learned from the high-volume product may transfer to lower-volume products with more complex design and higher value added. The high-volume devices are called technology drivers and are usually memory devices (DRAMs, SRAMs, and EPROMs) due to their standard configurations.

TABLE 3

*Historical worldwide wafer fab equipment,  
semiconductor capital spending and production,  
1982-1994 (in million of U.S. dollars)*

YEAR	Wafer Fab Equipment	Capital Spending	Semiconductor Production
1982	1,414		15,621
1983	2,121	5,666	21,537
1984	3,523	8,107	28,825
1985	3,357	7,299	28,132
1986	2,713	5,129	34,102
1987	3,137	6,435	41,833
1988	4,984	10,088	54,987
1989	6,011	12,464	59,184
1990	5,867	12,520	59,328
1991	6,014	12,995	64,453
1992	5,089	11,601	70,461
1993	6,876	14,150	87,662
1994	10,755	22,356	112,361

Source: Dataquest (June 1995)

Note: Thanks to Clark Fuhs of Dataquest for the data.

<sup>17</sup> For instance see Webbink (1977), Howell et al., (1988), Gruber (1994), and Flamm (1996), and the references cited there.

The semiconductor industry is highly capital intensive (TABLE 3). Since 1986 the average U.S. semiconductor firm was contributing between 13% and 15.6% of sales revenues to capital expenditures, i.e., property, plant and equipment (SIA, 1993, p. 39). Further, the total cost of a wafer fabrication facility has increased from 30 million dollars in the mid-1970s to 300 million dollars in the mid-1990's (Flamm, 1996, p. 16, table 1-2). The implication of these increased capital expenditures is that entry to and exit from the industry has become prohibitively expensive.

TABLE 4

*Various average expenditures as a percent of sales revenues.*

Year	R&D S,G&A <sup>1</sup>		Production cost (less depreciation)	Depreciation
1978	8	18.3	57.1	6.5
1979	7.1	17.8	55.7	6.5
1980	7.4	18.8	53.9	6.1
1981	9.6	21.0	57.1	7.8
1982	10.2	21.8	59.5	9.2
1983	9.9	19.2	55.6	8.4
1984	9.8	16.5	52.3	7.6
1985	14.4	21.1	59.9	13.4
1986	14.8	22.1	56.2	13.1
1987	12.9	20.2	23.9	10.6
1988	11.1	18.6	48.6	9.0
1989	12.3	19.1	51.8	10.1
1990	13.7	19.2	55.6	10.6
1991	13.8	18.9	53.6	11.3
1992	12.4	18.7	55.3	10.3

Sources: Column 2: SIA 1993 Annual Databook, p. 28, Column 3: SIA 1993 Annual Databook, p. 27, Column 4: SIA 1993 Annual Databook, p 25, Column 5: SIA 1993 Annual Databook, p. 26.

Notes: <sup>1</sup> Selling, general and administrative costs

Conversely, due to scale and learning economies, the variable cost in the industry is decreasing over time. In addition, the basic inputs of production, transportation and distribution costs are quite low (Tyson, 1993, p. 89). Further, firms try to reduce the expense of assembly and final testing that tends to be labor intensive by moving them to low-labor cost areas. TABLE 4 provides information on different expenditures as a percent of sales. As already noted, technical progress is a main characteristic of the industry, which makes investment in R&D a major expense. TABLE 5 indicates that in 1986, R&D at 13% of sales is a higher percentage of sales than in any other industry.

TABLE 5

*1986 R&D Expenditures as a percent of sales*

INDUSTRY	R&D
Semiconductors	12.2
Computers	8.3
Drugs	7.8
Software/Services	7.7
Peripherals	7
Instruments	6.7
Leisure Industries	5.9
Telecommunications	5.1
Office Equipment	4.8
Aerospace	4.5
Electronics	4.4
Chemicals	4.1
Automotive	3.7
ALL INDUSTRY	3.5
COMPOSITE	
Electrical	3.3
Machinery	3.3
Oil service/Supply	3.3

Sources: Business Week, June 22, 1987, adapted from Howell et al., 1988

Note: Business Week Data understates actual semiconductor R&D because included in the denominator are sales of products other than semiconductors for multiproduct firms.

## 4 NEC: a case study

In June 1997, in an elegant and fully equipped conference room at NEC's new Tokyo headquarters, Vice President Yoichi Numata outlined the corporation's vision for the new millennium: to become a leader in multimedia.<sup>18</sup> In NEC's vision, this is the market where supercomputers process information, where image is the main characteristic for the user, and where the borders between hardware and software begin to fade. NEC enters its second century of operations with a clear vision and, as will be shown, information technology is of strategic importance to accomplish this objective.

Founded in the late nineteenth century, NEC is one of the most successful companies not only in Japan but worldwide. Its major product groups are communications systems and equipment, computers and industrial electronic systems, and electron devices. These three categories comprise the Communications and Computer (C&C) operations, which in the last five years represented 95% of its sales. NEC also produces home appliances, VCRs, TV sets, video projectors, video games, and car electronic products. The share of sales by product category is given in TABLE 6.

TABLE 6

*Share of net sales by product category (in percentage terms)*

	1992	1993	1994	1995	1996
Communications systems	27	27	27	27	28
Computers systems	52	51	50	47	44
Electron devices	16	17	18	21	24
C&C operations (total)	95	95	95	95	96

<sup>18</sup> Personal interview, June 1997, Tokyo, Japan.

Other operations	5	5	5	5	4
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Source: Adapted from NEC (1996d)

In 1996 NEC was the fourth largest supplier in computers after IBM, Fujitsu, and Hewlett-Packard; it was fourth in telecommunications after Alcatel, Lucent Technologies, Erickson, and Motorola (NEC, 1996d). In addition, NEC was the second largest supplier of semiconductors worldwide after Intel in 1995 and 1996 (TABLE 7). This is not surprising since NEC established semiconductors as the basis for integrating communications and computer systems. A strong semiconductor base allows NEC to achieve higher quality and lower cost in computers and communication equipment. Leadership in the development and manufacturing of semiconductors, therefore, is essential to NEC's corporate success. NEC's impressive performance is also evident in the selective financial data provided in TABLE 8.

TABLE 7

*Worldwide top five merchant semiconductor sales leaders*

	1992	1995	1996	IC Sales (\$M)	%change 95-96
Intel	3	1	1	17,800	31
NEC	1	2	2	10,250	-16
Toshiba	2	3	3	8,725	-18
Hitachi	5	4	4	8,350	-15
Motorola	4	5	5	8,025	-7

Source: Adapted from ICE 1997

NEC has accomplished this leadership by diversifying into a wide range of products, which allows the company not to depend exclusively on a single product (For a complete line up of NEC semiconductor products see EXHIBIT 1 in the Appendix A). In the semiconductor

segment specifically, its ability to produce memory-devices, logic-devices, and microprocessors distinguishes NEC from other competitors. For instance, the Korean firms Samsung and Hyundai and the U.S. Micron Technologies focus on DRAMs, while Fujitsu targets cellular products. Diversification also permits NEC to offer their customers a full product line. Thus, NEC supplies even large customers in such a way that they have little incentive to move to other suppliers. This provides a stabilizing effect against the industry's volatile demand.

The following section begins with a brief overview of the Japanese semiconductor industry. It then examines NEC from two different perspectives: its historical evolution and its organizational structure. The final part examines NEC's software and information systems strategies that it uses to gain and sustain competitive advantage.

TABLE 8  
*NEC: Five-year historical financial statistics*  
(In millions of Yen)

Year ended March 31	1992	1993	1994	1995	1996
Net Sales	3,773,850	3,514,979	3,579,787	3,769,357	4,427,272
Cost of sales	2,520,783	2,394,247	2,463,607	2,557,536	2,980,718
R&D expenses	302,363	275,017	261,659	266,006	298,713
Selling, general, and administrative expenses	1,331,619	1,093,596	1,038,699	1,056,052	1,168,672
Capital expenditures	321,727	230,787	230,069	300,220	401,999
Depreciation	235,646	226,456	213,380	222,780	260,247
Operating income	121,448	27,136	77,481	155,769	247,802
Net income (loss)	15,276	(45,160)	6,606	35,316	77,166
Total Assets	4,081,217	3,978,899	4,039,809	4,151,320	4,683,120
Shareholders' equity	878,353	805,833	782,061	790,749	878,852
Shares outstanding <sup>1</sup>	1,539,143	1,539,417	1,540,169	1,541,322	1,546,193
Shareholders	147,482	161,838	168,115	164,218	160,139
Return on equity <sup>2</sup>	1.70%	-5.40%	0.80%	4.50%	9.20%
Number of employees	128,320	104,969	147,910	151,069	152,719

Notes: <sup>1</sup> Thousand of shares

<sup>2</sup> Return on equity = Net Income / Total Shareholder's Equity

Sources: NEC, This is NEC 1996

#### **4.1 *The Japanese semiconductor industry***

Japanese electronics firms began the production of transistors in the mid-1950s and the production of ICs in the mid-1960s. Two types of firms entered the production of semiconductors: existing producers of vacuum tubes and new semiconductor manufacturers (Tilton, 1971). However, the evolution of the Japanese semiconductor industry is quite different than that of the U.S. industry, which focused primarily on the defense and military sectors. The small domestic military and defense markets forced Japanese semiconductor firms to focus on commercial applications. Consequently, foreign markets became very important outlets for semiconductor products.

Japan has followed the progress of the U.S. semiconductor industry closely. At first, Japanese firms imitated and reverse-engineered most of the U.S. industry's innovations. In the 1960s, Japanese firms focused their production on inexpensive, low-quality transistors for final consumer products. However, by the end of the 1970s the industry moved towards state-of-the-art production of semiconductor devices, mainly memories, for a variety of industries like computer and telecommunications. Still, due to its initial small base of the industry, its growth rate was exceptional. Over the 1970-84 period the average annual growth rate was 17% (Kimura, 1988, p. 37). Nevertheless, a point, which has been the subject of considerable policy analysis and debate, is how this growth translated itself into the well-documented reversal between Japan and the U.S. in worldwide semiconductor shipments. U.S. firms, which in 1975 held 75% of worldwide semiconductor shipments, fell to 31% in 1992, while the Japanese and other Asian producers increased their share from 20% to 50% for the same period (Flaherty, 1984; Krouse, 1992). In addition, as TABLE 9 indicates, U.S. semiconductor consumption also decreased during this period.

Many analysts attribute a large part of this rapid development, growth and shift in global market share to the successful industrial policies of the Japanese government.<sup>19</sup> In the 1950s, the government supported the initial research on semiconductors that took place at Nippon Telegraph and Telephone Corporation (NTT) and the Ministry of International Trade and Industry (MITI) (Flamm, 1996, p. 40). In the 1960s the government established policies to protect the domestic market. Indeed, until the mid-1970s the government controlled the inflow of capital and technology, and it could place considerable pressure on Japanese producers and customers by informal meetings at ministries as well as through trade associations. Even after the removal of the formal entry barriers in the late 1970s, foreign firms found it difficult to break long-standing, traditional relations between producers, users, and governmental agencies. At the same time, however, the government wanted to build a globally strong Japanese semiconductor industry. To do so, the government recognized the need for vigorous internal competition. Thus, while protecting the domestic market from foreign entry, it fostered competition among the Japanese firms.

In addition, analysts have outlined a series of factors that have contributed to the different evolution of the industry in Japan and the U.S.<sup>20</sup> These arguments focus on the vertical integration and debt financing characteristics of the Japanese economy. Japanese firms have also made a greater effort to automate the production process as opposed to searching out low labor-cost areas for their assembly lines.<sup>21</sup>

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<sup>19</sup> Flamm (1996), Chapter 2, provides a detailed account of the government intervention and its effect on the development of the Japanese semiconductor industry. See also Borrus et al., (1983), Howell et al., (1988), Prestowitz (1988), and Tyson (1993) among others.

<sup>20</sup> For instance see Webbink (1977), Morris (1990), and Tyson (1993), among others.

<sup>21</sup> Morris (1990) points out that in 1973, the US had 128 offshore assembly plants whereas Japanese firms had only four.

Nevertheless, within the industry, leading producers follow different strategies with respect to the number and type of devices they produce and the end-users they focus on. Thus, Kimura (1988) cites several studies that identify groups of firms with distinct business strategies. NEC, Hitachi, and Toshiba manufacture a full product line, whereas Fujitsu, Oki, and Sharp do not. Furthermore, NEC, Fujitsu, and Oki emphasize devices used mostly on telecommunications and computer industries, whereas Hitachi, Toshiba, and Mitsubishi support the general electric and electronics equipment sectors.

TABLE 9

*Semiconductor sales in regional markets: 1982-1992*

	US market share (%)	Japanese market share (%)	European market share (%)	Rest of the world market share (%)
1982	44.37	28.17	21.13	6.34
1983	43.58	30.73	18.44	7.26
1984	44.44	30.65	18.01	6.90
1985	37.33	35.02	20.74	6.91
1986	31.85	39.63	20.00	8.52
1987	31.14	38.92	18.56	11.38
1988	29.74	40.30	17.89	12.07
1989	30.24	39.52	18.15	12.10
1990	28.51	38.81	19.01	13.66
1991	28.21	38.28	18.50	15.02
1992	30.72	32.39	19.20	17.70

Source: Adapted from SIA 1993 Annual Databook, p. 13, and author's own calculations

#### **4.2 The history of NEC**

NEC was founded in 1899 as a joint venture with the Western Electric Company of the U.S., the first Japanese joint venture with foreign capital.<sup>22</sup> Initially, the acronym stood for Nippon

<sup>22</sup> This section relies heavily on Kobayashi (1991), and NEC (1996a).

Electric Company, Ltd., but it was renamed NEC Corporation in 1983. In 1925, Western Electric sold its shares to International Telephone and Telegraph (ITT) of the US, which acquired almost 60% of NEC. ITT held its stake in NEC until the early 1960s after which NEC grew as an independent entity. NEC also strengthened further its affiliation with the Sumitomo group, which it had established in the 1930s.

NEC's original business objective was to import and manufacture telecommunication equipment. After World War II, it participated in Japan's rapid domestic expansion due to the country's reconstruction. NEC entered the semiconductor market in 1958 by building a large-scale transistor plant and capturing 15% of the domestic market the following year (Flamm, 1996, p.45). It also expanded in the home appliance market by establishing the New Nippon Electric Company Ltd., presently NEC Home Electronics, Ltd. However, its main client was the Japanese Communication Ministry in its different forms [(currently Ministry of Post and Telecommunications (MPT)]. For instance, Nippon Telegraph and Telephone (NTT) was the single most important client for NEC from NTT's formation in the early 1950's until its partial privatization and reorganization in the mid 1980's, sometimes representing over 50% of NEC's sales.

In the 1960s and 1970s, NEC expanded both by entering new international markets, which included establishing worldwide subsidiaries, and by manufacturing new products. It established a marketing subsidiary in the US (Nippon Electric New York, Inc.), and a manufacturing subsidiary in Mexico (NEC de Mexico). Two new areas that held great interest for NEC were computers and software. Thus, in the 1960s it formed an unsuccessful alliance with Honeywell, hoping to support its diversification into computer equipment and software. In addition, NEC formed alliances with Hitachi and Fujitsu to develop computers. However, since

these computers were dependent on using more advanced semiconductors, NEC also became one of the main forces behind the joint effort of the Japanese government and the private sector to develop VLSI chips in the mid 1970s.<sup>23</sup>

A new period for NEC began with the articulation of the "C&C" (Compute and Communicate) corporate strategy announced by its chairman, Koji Kobayashi, in 1977. This innovative approach envisioned integrating computer and communication technologies through semiconductors (Kobayashi, 1991). By implementing this strategy, NEC became one of the leaders in the production of semiconductor devices in the following decade. It established manufacturing units for semiconductors in Dallas, Texas and for VCRs, printers, and TV sets in United Kingdom. In Japan, it enjoyed great success from the production of mainframe systems and portable computers.

The 1990s began with a new location for the NEC headquarters in Tokyo, and an operations expansion to other Far Eastern countries with a manufacturing joint venture for digital electronic switching systems in China, and a coordination center in Singapore. In addition, the 1990s brought an expansion of the C&C strategy to incorporate the responsibilities and contribution of NEC, as a "corporate citizen" (NEC, 1996a, p. 4).

This expanded orientation of its C&C strategy has resulted in net worldwide sales, as of March 31, 1996 of \$41 billion and capital of \$1.8 billion produced by eighty-nine domestic subsidiaries, thirty-eight overseas consolidated subsidiaries, and 152,719 employees (See TABLE 8 above and NEC, 1996a). Concurrently, NEC has developed a sophisticated organizational structure to manage and coordinate its diverse entities and activities as well as to constantly improve quality and lower costs firm wide.

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<sup>23</sup> For this and other government oriented R&D programs in Japan, see Howell et al., (1988) and Flamm (1996), chapter 2.

### **4.3 Organizational structure**

The origins of the current organizational structure can be traced to the substantial management reforms introduced by the then “new” President of NEC, Koji Kobayashi, in the mid 1960s.

First, he introduced more integration within each operating division by defining it as "a single unit containing all three functions---engineering, manufacturing, and marketing" (Kobayashi, 1991, p. 17). Second, he introduced the concept of "zero-defects," a practice originated at U.S. defense related firms like Martin-Marietta and Hughes Aircraft (Kobayashi, 1991, p. 20-21). Third, he introduced maximum employee involvement in product and process improvement (Kobayashi, 1991, p. 21-22).

However, as noted above, his most important contribution is the 1977 articulation of the C&C corporate philosophy, which integrated the computer and communication technologies with semiconductors. During the last twenty years, the C&C vision has evolved from a technology-oriented concept to a concept that incorporates the human factor in order to combine the engineering, manufacturing and marketing divisions to produce and deliver goods with zero-defects. With respect to the semiconductors, as production approaches the zero-defect level, the yield is high, and quality is well regarded in the market. This improves the cost and reliability of the segments using these chips, such as computers and telecommunications, resulting in an increase in market-share and yields and a decrease in costs for the semiconductor segment.

NEC is organized into five marketing and eleven operating groups (See EXHIBIT 2 in the Appendix A). All divisions receive professional and technical support from the corporate-staff group (NEC, 1996a,d). The marketing groups are targeted towards the international and three domestic markets (NTT, Government and public sector, and Other domestic sales.) The fifth group coordinates the advertising and promotional activities in these markets. The operating

groups are targeted towards medium- and long-term R&D,<sup>24</sup> development and manufacturing of specific equipment,<sup>25</sup> and special-projects for distinctive marketing and engineering projects as well as multimedia services.

Within the Semiconductor Group the company's efforts are concentrated in three dimensions: operational management, development of new technology, and global operation (See EXHIBIT 3 in the Appendix A). More specifically, the Semiconductor Group is organized into six divisions: a planning office, information systems center, logistic management center, quality assurance, and the division which is concerned with R&D, production, marketing, and sales of semiconductors. The R&D operations in the latter division are distinguished according to the different types of semiconductors, i.e., discrete, memory, and logic products. With respect to the marketing and sales division, there are eleven independent subdivisions with offices throughout the world.<sup>26</sup>

There is a trade-off between the management principle giving independence to each operating division, as set by chairman Koji Kobayashi in the mid 1960s, and the need for close coordination and cooperation of these divisions for efficient decision making. This need for integration over products and countries demands a unified communications process. For this reason, NEC Semiconductor Group adapted the English language as a means of communication among its manufacturing and marketing plants around the world. Thus employees in all levels of production and management who join the Semiconductor Group are expected either to know

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<sup>24</sup> Operating groups focusing on research are R&D, C&C Software, and Production-engineering-development groups.

<sup>25</sup> These operating groups are: C&C product technologies group for communications, factory automation, and control systems; C&C Systems group for customized solutions; Computer group; Personal C&C group; Semiconductor group; Electronic component group; and home electronics group.

<sup>26</sup> The eleven subdivisions are: Semiconductor Marketing; Semiconductor Solution Engineering; Semiconductor Sales Engineering; 1st Semiconductor Sales; 2nd Semiconductor Sales; 3rd Semiconductor Sales; C&C Semiconductor Sales; ULSI Device Development Laboratories; VLSI Manufacturing Engineering; VLSI Packaging and Testing Engineering; and LSI Manufacturing.

English, or to master the language within the first year of their employment. Even though this is quite remarkable in its own right, it is understandable. In an industry characterized by global competition, rapid technological change, and the need to establish production and marketing units in different geographic locations, the clear and rapid accumulation and distribution of information are essential. In addition to its geographic expansion, however, NEC has diversified in the types of goods it produces. This will be examined next.

#### **4.4 Product range and manufacturing**

The semiconductor product portfolio of NEC extends from transistors and diodes to dedicated and hybrid ICs (See EXHIBIT 1 in the Appendix A). In memories it produces DRAMs, SRAMs, ECL RAMs, Mask ROMs, and EPROMs while in semi-custom ICs it produces gate-arrays, cell-based ICs, analog masters, etc. In microcomputers, it produces 4-bit, 8-bit, and 8-16-bit single chip microcomputers, DTS microcontrollers, V and V<sub>R</sub> series microcomputers, peripheral LSIs, etc. The memory, semi-custom IC, and microcomputer high value added categories represent more than 80% of sales in terms of value. In addition, NEC produces optical devices, microwave devices, high-frequency consumer devices, and general-purpose linear and digital ICs. About 30% of the total semiconductor production is for internal use, while the remaining 70% is distributed in the merchant market.

In 1996, eighteen design and manufacturing centers that were located in Japan and overseas focused on the production of semiconductor devices. Within Japan, manufacturing units were found in Fukui, Fukuoka, Hiroshima, Kansai, Kumamoto, Kyushu, Oita, Sagamihara, Tamagawa, Yamagata, and Yamaguchi. Overseas, manufacturing units were located in Ireland,

the United Kingdom, Hong Kong, Malaysia, Singapore, Indonesia, and California. The Overseas Semiconductor Plants Coordination Division oversees these facilities outside Japan.<sup>27</sup>

The reasons we observe this globalization of the Semiconductor Group are as follows. First is the need to compete in quite different markets such as the North American and the European semiconductor markets. Kobayashi (1991, p.179) emphasized this objective by stating: “Have your production and marketing facilities as close to your market as possible.” Second is the independence of the different stages of production that allows for such geographic diversification. As shown earlier, the design of a semiconductor need not be completed in-house, and similarly, its assembly and final testing do not need to take place in the same location as its manufacturing. Third, due to the importance of foreign markets, Japanese firms use foreign direct investment to enter a sector and reduce the effect of changes in the foreign trade policies. Finally, Japanese firms use offshore production facilities to hedge against exchange rate risks. For instance, due to the recent appreciation of the Yen, more than half of the Japanese TV and VCR production is taking place offshore (EIAJ, 1995, p. 3-1).

Generally, NEC and its subsidiaries’ plants are dedicated production facilities. However, NEC has been able to operate its plants in a “flexible” fashion. While other competitors were forced to reduce the price of their products in periods of declining demand, NEC was able to partially offset this effect by redirecting capacity to segments where the decline of the demand was less severe. Although the technical details are not clear, analysts of the Japanese semiconductor market believe NEC can more easily adjust its capital and labor force so as to

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<sup>27</sup> The LSI design centers outside Japan are Portland, Mountain View, Santa Ana, Dallas, Chicago, Raleigh, Boston, Milton Keynes, Paris, Eindhoven, Dusseldorf, Stuttgart, Milan, Munich, Stockholm, Singapore, Hong Kong, and Taipei. See NEC (1996c), p. 13.

modify the type of device produced.<sup>28</sup> For instance, ICE (1997, p. 2-39) reports that due to the decline in DRAM prices in 1996, NEC altered some DRAM facilities to produce ASICs (Application Specific ICs) for which the demand was still relatively good. It generally takes about two months to switch the production of a facility from one device to another. NEC's objective, however, has been to decrease this time to a month, which gives them comparative advantage in the marketplace.<sup>29</sup>

In conclusion, by diversifying its product line and increasing the flexibility of its production process, NEC is not held hostage to the performance of a single product. Furthermore, in response to the global nature of the industry, NEC has expanded its locations worldwide. Thus, by following a typical Japanese marketing strategy of surrounding the consumer with a large spectrum of products, NEC has established a business relationship with large buyers across countries and products. The result is a better understanding and improved projections of market conditions, which allow NEC to adjust production accordingly. The immediate implication is that in periods of lower demand, instead of decreasing the price to clear unwanted inventory, NEC can modify its production to both, keep inventories lower, and meet shifts in demand.

The element that connects all the above strategies and directs them to a successful result is NEC's flexible manufacturing system. As noted above, this requires a unified communications process over products and countries. In terms of human resource communication the choice of the English language is indisputable. The choice of software for communication and information systems is based on similar criteria.

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<sup>28</sup> I would like to thank Hiroyuki Iba of Nikko Research Center (NRC) who on the morning of July 4, 1997, outlined the Japanese Semiconductor Industry and NEC's role within it and illustrated the concept of flexible manufacturing.

## **5 Using information systems as competitive tool**

In the semiconductor industry, software and information systems are used extensively, both in the manufacturing and marketing of devices. It is not surprising, therefore, that NEC's management has a clear vision of its software needs and thus a clear strategy for software and information systems. An important decision in this regard has been whether to adapt commercially available packages or to develop customized software, as is true among many Japanese companies (Rapp 1995b).

NEC has resolved this question by employing a combination of customized and packaged software with and without a customized interface. In making these software decisions, NEC divides its software and information systems needs into two categories. The first includes the design of the chip. The second contains the manufacturing, marketing, and sales of the semiconductor products.

### **5.1 Chip design**

Computer-Aided-Design (CAD) software is used in chip design, which is the most costly and time-consuming stage of semiconductor development and manufacturing. Chip design is also the stage at which imaginative and creative elements are introduced in the conception of a device. This makes the human interface the most important characteristic of such software. Therefore, CAD is required to minimize costs, increase performance, and support many designers. In addition, CAD has to allow for integration with the commercial part of the business as well as NEC's in-house tools. Utilizing an open architecture or open CAD system best satisfies the required mix of individuality and commonality.

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<sup>29</sup> The importance of flexible production for NEC was presented to us by Mr. Yoichi Numata, Vice President of

The computer network for LSI design consists of workstations, network, and personal computers (PC) hardware platforms. Currently, 85% of the software expenditure is for the workstation's UNIX based operating system, while 10% goes to software dedicated to networks. The remaining 5% is to meet PC requirements. The latter are the Windows-NT and OS/2 operating systems. However, despite the low current expenditure on PCs, the intention is to move exclusively to PCs in the near future.

When choosing chip design programs, the criteria used are technology (that is, functioning and performance), price, and inter-operability, in that order. This has resulted in adapting a combination of packaged software that is managed by a customized interface (See EXHIBIT 4 in Appendix A). NEC develops only 20% of the software used in chip design, satisfying the remainder of its needs from commercially available packages. NEC realizes that in terms of chip design, specialized firms have a comparative advantage in developing technically superior software products in an efficient way. Therefore, NEC develops that part of the software that serves to tighten the linkage between design and production process. Half of this customized interface is developed by third parties, while NEC and its subsidiaries develop the remaining half in equal proportion.

## **5.2 Production and marketing**

The above picture is reversed in the production and marketing aspects of the Semiconductor Group. Here NEC perceives that tacit knowledge, corporate philosophy, and firm culture have to be integrated into the information systems. In other words, software packages must reflect and facilitate NEC's philosophy. Therefore, information systems have to be customized.

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NEC, Akihiko Morino, Chief Engineer of the Semiconductor Group of NEC, and Yoshitada Fujinami, Senior Manager of NEC in our meeting, June 23, 1997 in Tokyo.

In production and marketing, software must facilitate the managing and sharing of information. In both cases large data sets need to be stored and processed, so the obvious software requirements are reliable operation and large storage space. In addition, cost minimization is achieved by following a strategy where the existing information system is used to the maximum extent. Currently, this results in 70% mainframe usage while the remaining is network servers. However, NEC believes that the future is in distributed systems. Therefore, it estimates that within the next five years about 70% of production and sales software demands will be satisfied with distributed systems.

The second requirement is associated with the reliability of the software's operation. With respect to the production of a device, there are two dimensions of interest: production control and production operation. The former applies to production planning, purchase orders, inventory levels, and device shipments. Production operations apply to the automatic line control. The integration of these activities leads to feedback cycles that increase productivity by reducing defects, cycle times, inventory levels, and delivery time.

The priorities for choosing software for production and sales are reliability, technological functions, performance, and price. Given the importance of information systems integration between the marketing and operating groups, the software needed is internally developed. Thus, 90% of the software is developed by NEC or by NEC affiliates. Of this, 55% is developed by subsidiaries while 30% is developed by third parties under contract to NEC. Most of the commercially available packages are database management systems or application software used in overseas subsidiaries. Commercial software is also used in the production equipment where the semiconductor equipment manufacturer develops the controlling software. NEC's proprietary system links these machines and their programs.

An important outcome of this computerization and the strategic use of information systems is increased efficiency, often manifested by a decrease in inventory costs. At the same time, a new phenomenon has occurred: an increase in in-process inventory. NEC and other Japanese firms, though, refer to in-process inventory as “buffer stocks.” An increase in in-process inventory is usually perceived as inefficient, the outcome of a “batch” production system not yet synchronized.

However, NEC and other leading Japanese firms offer another explanation based on arguments about capacity utilization and the limits of the assembly line. Under this view, using buffer stock shortens the production cycle and increases the accuracy and precision of information sharing, so equipment can be used more intensively. In addition, there is a reduced risk of being stuck with large inventories of obsolete devices when demand changes. Thus, this “controlled production” reduces overall inventories and lowers production costs due to better factor utilization, allowing NEC to respond more quickly to the industry’s rapid changes in demand.

Here is how it works. A few years ago, NEC, Toyota and some other leading Japanese producers began to recognize that their ability to get large productivity gains via improvements in their lean production systems was being limited by the production line itself. For example, in auto production, the assembly line moves at a certain speed that is limited by the slowest task which cannot be improved further, or cannot be coupled with another task at an assembly point. In semiconductors, the batch size has been limited by the smallest capacity piece of equipment. As the cost of semiconductor equipment rose, the opportunity cost of this unused capacity became very expensive. The solution was to break the production line and run each piece of equipment or assembly segment more fully, even if this meant some increase in buffer stocks or

in-process inventories. However, controlling this process and the size of the stocks and costs requires sophisticated information processing. Once in place however, it can be used to order parts from suppliers etc., thus building on traditional lean production systems.

One particular benefit of this approach to NEC has been the discovery that certain initial aspects of their production process are common to a variety of devices. Thus, by increasing their buffer stocks at this stage of production, they have more flexibility when demand changes, since they can switch final production from one device to another in less time. In addition, as semiconductor demand and prices can change rapidly, their ability to shift production more quickly than their competitors means they are less likely to experience severe price erosion. In turn, better margins improve the cash flow available to support R&D, marketing and capital investment. This was demonstrated in 1995 when NEC was the only large Japanese producer to avoid a loss due to the reduced demand for DRAMs because of their ability to switch to ASICs, for which demand was still relatively good. In effect, their improved production flexibility supports their wide product line through lower costs and better time to market, while their wide product line supports their improved flexibility through market contact and information flow. NEC's information system links this controlled process together and makes it possible.

Part of this process was forced by NEC's need to become a global company, since the semiconductor business (as well as its C&C business) was both global and scale sensitive. As Mr. Kobayashi [(1991), p. 175] stated:

Becoming a global corporation meant upgrading our technology, streamlining production, and strengthening our sales techniques through competition with the leading companies of the world. By honing our skills in the international marketplace, we learned just what foreign markets wanted and how to reflect these needs in our overseas business strategy.

Importantly, honing these skills over time required selecting software packages and developing appropriate criteria to make these software selection decisions. At NEC, software engineers with a broad knowledge of the semiconductor business establish these criteria. To find the most important and efficient criteria however, many face-to-face meetings within the semiconductor group are conducted, since these decisions affect the entire semiconductor process from development through sales and service. In addition, the choice of a particular software package can be assessed only after analyzing carefully the impact it has on the entire process. Indeed, this clarity of vision appears to be a hallmark of the controlled production paradigm.

At the same time, in evaluating software performance, the characteristics used are not general but application specific in that they depend on the specific area where the software will be employed. So with respect to using a particular software package, there is no real evaluation process for a software package already being used. This is because before adopting the software, NEC has extensively researched all existing customized and semi-customized packages. Thus NEC is always sure the best available software package for its needs has been chosen. Nevertheless, the corporation does constantly examine the software market for future orders, considering all the above mentioned characteristics during the performance evaluation.

## **6 Concluding remarks**

In contrast with the results of earlier studies, NEC appears to use a software strategy that combines customized and packaged software. Up until the mid-1990s, most of Japan's major software users pursued a software policy heavily reliant on customized software. This was due to an historical legacy based on the multiplicity of mainframe operating systems and the firm's own development of software reflecting its culture and organization (Rapp, 1995). Indeed, based on

this fact, it was hypothesized that leading Japanese software users would be marginally better at adapting and developing their software and information systems so as to capture their tacit organizational and business advantages.

However, the results of this case study indicate that NEC is in fact developing a more mixed approach to software selection that incorporates more packaged software.<sup>30</sup> NEC can do this because of its understanding of its business and information support requirements. This clarity of vision permits NEC to benefit from less expensive packaged software, while enhancing its tacit and organizational strengths through the development of customized software, when no suitable package is available. This was clearly outlined in NEC's approach to selecting production software.

In conclusion, the present study offers three main results. First, both customized and packaged software is used by NEC. Second, NEC consciously and successfully uses software to sustain competitive advantage by linking its software strategies directly to its overall management goals. Finally, a new production practice seems to emerge, the controlled-production, where the segmentation of the production line and subsequent control of each segment allows the firm to be more efficient and responsive to changes in the market conditions.

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<sup>30</sup> This is also supported by the other Sloan case studies as well.

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## **Appendix A:**

### *EXHIBIT 1: NEC's Semiconductor Products*

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Source: "Software and Information Systems for Semiconductor Business." Presentation by Mr. Akihiro Morino, NEC Corporation, June 26, 1997.

*EXHIBIT 2: Organization Chart for NEC*

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Source: Adapted from NEC (1996a).

*EXHIBIT 3: Organization Chart for the NEC Semiconductor Group*

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Source: "Software and Information Systems for Semiconductor Business." Presentation by Mr. Akihiro Morino, NEC Corporation, June 26, 1997.

*EXHIBIT 4: Open CAD Chip Design System*

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Source: "Software and Information Systems for Semiconductor Business." Presentation by Mr. Akihiro Morino, NEC Corporation, June 26, 1997.

## Appendix B:

### SUMMARY ANSWERS TO QUESTIONS FOR NEC

	QUESTIONS	YES	NO	NOT CLEAR
<b>A</b>	<b>GENERAL MANAGEMENT AND CORPORATE STRATEGY</b>			
1	Has the firm integrated software into their management strategy, including using it to institutionalize organizational strengths and capture tacit knowledge on an iterative basis?	x		
2	Has the firm succeeded solely on the basis of its software strategy?		x	
3	Does the firm believe some customized software and its close organizational integration enables the company to capture and perpetuate on a more consistent basis certain tacit knowledge and unique corporate features, i.e. core competencies, that account for its continued success in the marketplace with reliability and repetition important elements in their thinking?	x		
4	Is the firm's software strategy successful because it is a well managed company that introduces software innovation when it serves corporate goals for enhancing productivity, inventory management or customer relations within its industry?	x		
5	Does the firm generally meet established criteria as a quality organization such as: effective organizational self assessment, use of project and especially cross functional teams, improving quality outcomes through reducing uncertainty, rapidly diffusing learning throughout the organization including the use of software and information technology, effective implementation of organizational and technical change, facilitating change via evolution rather than revolution or reengineering , emphasizing participatory management, having process excellence, using value added analysis, actively doing benchmarking, constant organizational improvement, commitment to concrete realistic goals, effectively managing a dynamic iterative experimental process through goal setting, training and constant consultation?			x

- |    |  |   |
|----|--|---|
| 6  | Does the firm plan in detail for world class operational excellence including the contribution of software and information technology to the allocation of resources?  | x |
| 7  | Do their planning systems enable management to make better business, operating and resource allocation decisions, including those related to software and IT, with a link to resource valuation techniques?    | x |
| 8  | Do they focus on a small number of priorities, usually three or fewer, with a well defined, cascaded system reaching from the commitment of senior management to the department level with associated metrics? | x |
| 9  | Is the firm a “high performance” workplace for services?   | x |
| 10 | Is there a heavy emphasis on improving process through using software?   | x |

**B                    INDUSTRY RELATED QUESTIONS**

- |    |  |   |
|----|--|---|
| 11 | Are industry economics and competitive dynamics an important strategic driver for the firm and for its use of software and information technology in that IT has been adapted to the firm’s particular industry and competitive situation? | x |
| 12 | Do industry paradoxes exist such as: declining stock prices, manufacturing improvements that create product improvement difficulties, or employees’ active product use that retards improvements?  | x |

**C                    COMPETITION**

- |    |  |   |
|----|--|---|
| 13 | Is software a significant and successful input into the firm’s competitive performance?  | x |
| 14 | Does the firm explicitly and consciously perceive the implications of their software strategies and use on their competitiveness and business success?   | x |
| 15 | Are there direct links between their software strategies and overall management goals?   | x |
| 16 | Do customers, affiliates, competitors, industry analysts, government officials, industry associations and suppliers perceive the competitive benefits or impact of the firm’s use of information technology? | x |
| 17 | Has the firm gained first mover advantages through successfully introducing software related innovations?  | x |

## D INFORMATION TECHNOLOGY STRATEGY

- |    |  |   |   |
|----|--|---|---|
| 18 | Is firm a sophisticated software user that consciously designs and implements a software strategy to achieve competitive advantage?  | x |   |
| 19 | Does the firms utilize several types of software input alone or in combination to achieve competitive advantage?   | x |   |
| 20 | Does the firm's system work to rapidly uncover barriers to implementation, including using new or improved software, while generating cross-functional and hierarchical consensus so measured goals can be achieved?   |   | x |
| 21 | Is leadership at different levels actively involved in driving software planning, assessment and deployment with regular progress reviews that link plans, goals, benchmarks, metrics, milestones, resources and responsibilities?   | x |   |
| 22 | Does the system allow for flexibility and innovation as well as change and individual efforts provided they meet goal, planning and metric criteria?   | x |   |
| 23 | Is there a clear vision making project and new product software selection straightforward and closely related to strategic goals and processes?  | x |   |
| 24 | Does this software strategy involve a conscious and clearly defined reliance on customized and semi-customized software in addition to packaged software with specific criteria and goals for selecting each type, and do they have ways to measure this so that the firm knows customized software achieves functional or market gains that justify the additional expense, including related costs of integrating customized and non-customized software into a single information system? | x |   |
| 25 | Does the firm use option valuation methods to manage uncertain and random outcomes since this appears to be at the software implementation frontiers even among very well managed companies?   |   | x |
| 26 | Does their strategy include increased use, development and integration of industry and company specific vertical application software and embedded software in its production and delivery processes to improve competitiveness?   |   | x |
| 27 | If the firm has an embedded software strategy, is this integrated or interactive with their other software and overall business strategy in ways affecting production, product design or service that improve quality and costs long term?   | x |   |
| 28 | Do they favor increased outsourcing of software design and development?  |   | x |

- |    |  |   |
|----|--|---|
| 29 | Does the firm believe large-scale outsourcing by many US companies assumes those firms' information systems development need not be integrated with their business organization and that they view their information systems as generic products best developed by outside vendors who can achieve low cost through economies of scale?  | x |
| 30 | Do they in turn believe this is a mistake by their competitors that gives them a long-term and sustainable competitive advantage over such companies because they believe outsourcing surrenders a firm's strategic software options since systems service companies have an incentive to develop increasingly standardized products and are one step removed from the company's customers and business? | x |
| 31 | Has the firm established a software strategy that is open and interactive with its customers and/or suppliers?   | x |
| 32 | Has this enabled it to capture information or cost competitive externalities?  | x |

**E      INFORMATION TECHNOLOGY OPERATIONS**

- |    |   |   |
|----|---|---|
| 33 | Do participants own goals and are then committed to implementation strategies?  | x |
| 34 | Does the firm embed software into its production and delivery processes with competitive market implications?   | x |
| 35 | Is software technology tied to high speed telecommunications technology, allowing the firm to track, receive and deliver shipments or services directly or on-line without further handling or processing?          | x |
| 36 | Does it manage the potential risks of extensive use of software or open systems?  | x |
| 37 | Do they work to ensure consistency and reduce programming errors?   | x |
| 38 | Is informal interaction a key aspect of planning and implementation?  | x |
| 39 | Is the firm's system institutionalized and self-reinforcing with good communication and consensus building while software and IT play a role, including preventing retrospective justification or target reduction? | x |

**F HUMAN RESOURCE AND ORGANIZATIONAL ISSUES**

- 40 Does the firm pay close attention to systems training and organizational integration for all employees, reducing errors through improved consistency and staffing efficiencies across the firm since software can confound even routine operations? x
- 41 Does certain software require special HR competencies or education? x
- 42 Does the firm try to change human behavior to use software? x

**G PARAMETER METRICS (INVENTORY, CYCLE TIMES, & COST REDUCTION)**

- 43 Are goals or targets tightly linked to regularly reviewed metrics with inputs coming from all levels that are often cross-functional affecting large parts of the organization, e.g. cycle times, on-time delivery, and customer satisfaction? x
- 44 Does the firm have standard agreed ways to explicitly organize or manage this software selection process? x
- 45 Does the firm have agreed ways to measure and evaluate success in using software to promote business objectives such as unit cost, inventories, lower receivables, market share, model development times, or product pipeline? x
- 46 Are IT costs balanced against overall long-term productivity gains? x
- 47 Does the firm have methods to ensure increased customization costs result in lower costs downstream so that developing and using customized software makes sense? x
- 48 Has the firm created large interactive databases to allow automatic feedback between stages or players in the production and delivery process? And are these databases constantly being refined and updated on an interactive basis with actual performance results in a real time global environment? What are the competitive and metric impacts of this? such as reducing inventory costs and wastage while improving the quality of customer service? x
- 49 Has the firm used software to create beneficial feedback cycles that increase productivity, reduce cycle times and defects, and integrate production and delivery processes? x



customer base, or improved yields?

- |    |  |   |
|----|--|---|
| 65 | Does this leading IT user have explicit criteria for selecting package versus customized software and for semi-customizing software packages?          | x |
| 66 | Does this firm closely integrate or couple its software and business strategies beyond mere alignment?   | x |
| 67 | Does this firm closely integrate its organizational and HR policies with its software systems?   | x |
| 68 | Has NEC reorganized in order to successfully use software and information technology?  | x |
| 69 | Has NEC's software codified or built on existing organizational strengths or core competencies including HR alignment with business and IT strategies? | x |
| 70 | Has NEC embraced and integrated information technology as part of its business strategies and core competencies?                                       | x |
| 71 | Is NEC's MIS department integrated with the rest of the firm in terms of organization and decision making?   | x |