Disruptive innovation

- Value change and complementary change -

by

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M.S., Kyushu University, 1997
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Submitted to the Alfred P. Sloan School of Management
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ABSTRACT

I expand Christensen's concept and classify two disruptive technologies, company disruptive technology and product disruptive technology. The company disruptive technology is Christensen's definition itself. The product disruptive technology is the disruptive one outside his definition, for example the digital still camera (DSC). I will discuss about some cases, such as a case of high-end disruption, in this expanded definition.

Company disruption follows product disruption. Targeting "company" is useful for making strategies, but it is not enough to target only "company" disruptive innovation because the product disruption sometimes badly damages or kills companies.

Complementors, such as other products, law, environment etc, are also very important when we consider the disruptive technology, because they change the value criteria of the product performance. It is very important for us to take advantage of complementors in order to grow the disruptive technology.

Disruption is a process and it does not always disrupt everything. The disruption is limited in the case of value-change disruption and another disruption is usually required to disrupt a product which falls outside the immediate influence of the first disruption. The disruptions must be happen one after another to disrupt all in the case of the value-change disruption. Circumstances also limit the impact of product disruption. Therefore, it is very useful for one to check and consider a disruptive technology from the viewpoints of both the value criteria and the circumstances.

Thesis Supervisor: James M. Utterback
Title: David J. McGrath jr. Professor of Management and Innovation

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Table of Contents

Chapter Contents Page

1. Introduction

Charles H. Fine mentioned "The life span of the fecund fruit fly is so short that scientists can study genetic changes in hundreds of generations during a decade."[1] He applied this scientific approach to industry research and thus established the concept of "clockspeed". While reading his book, I remembered my friend who researched the functionality of high polymer in his university days. He could not observe his sample until the high polymer swelled completely after he arranged the sample; the process took a few months. However, another researcher introduced a microscope to observe a sample. The idea enabled him to arrange a tiny sample, to shorten its swelling time dramatically, and to execute his research efficiently.

Introductions of a new viewpoint and a concept often open up a new world to us. We can see the different type of disruption by treating performance and cost equally as variables, just as we treat pressure and temperature equally in physics. Introduction of the new concept of "complementor" allows us to assess the idea of a value-change disruption. Most of our activities interact unconsciously and affect each other like the universal gravitation. Each activity has interactions with its surroundings, and sometimes works on other activities and makes the activity mainstream. In this paper, we can see that the complemetor affects the customer value criteria and shows us the new world of the disruptive technology.

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[1] Fine, C. H., *Clock Speed*, Perseus Books, 1998, p. 4.

2. Company disruptive technology and product disruptive technology

2.1. Christensen's definition

2.1.1. Christensen's definition

Clayton M. Christensen defined two disruptive technologies; one is low-end disruptive technology, which was originally mentioned in his book "The innovator's dilemma".[2] The other is new-market disruptive technology, which was added recently in his book "The innovator's solution".[3]

His definitions of the low-end disruptive technology are as follows.

1. It always comes from the low-end market with cheaper cost and simple function.
2. It always has lower cost than the incumbent technology.
3. It always has lower traditional performance than the incumbent technology.
4. It always has higher ancillary performance than the incumbent technology.

He also defines the new-market disruptive technology as below.

1. It competes with nonconsumption and creates a new value network.
2. Its product should be cheap enough for people who don't have a conventional product to own or be more convenient to use compared to the conventional technology.

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[2] Christensen, C. M., *The Innovator's Dilemma*, Harper Business Essentials, 2003, pp. xviii-xx.

[3] Christensen, C. M., *The Innovator's Solution*, Harvard Business School Press, 2003, pp. 43-49.

3. Its innovation pulls customers out of a mainstream value network into the new one.

I will explain these disruptive technologies in detail in the following sections.

2.1.2. Low-end Disruption

Christensen classified new technologies which lead to innovations into two types of technologies, sustaining technology and disruptive technology. The sustaining technology is the technology which improves the performance of established products along the dimensions of performance that mainstream customers in major markets have historically valued. The sustaining technology rarely results in the failure of leading firms even though the technology is the most radical one.

On the other hand, the disruptive technology precipitates leading firms into failure. Disruptive technologies bring a very different value proposition to the market from the previous value proposition which was available in the mainstream market.[4]

Christensen also mentioned that many principles of good management, which are now widely accepted, can not deal with the disruptive technology and that good management was the most powerful reason why well-managed firms failed to stay on top of their industries. That is to say, these firms lost their leading position because they listened to their customers and because they carefully studied market trends and systematically

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[4] Christensen, C. M., *The Innovator's Dilemma*, Harper Business Essentials, 2003, pp. xviii-xx.

allocated investment capital to innovations that promised the best returns.[5] The reason of the failure is explained as follows. Since technologies can progress faster than market demand, suppliers often overshoot their markets because of their efforts to provide better products than their competitors and to earn higher price and margins.[6] It is shown as a framework in Figure 2-1.

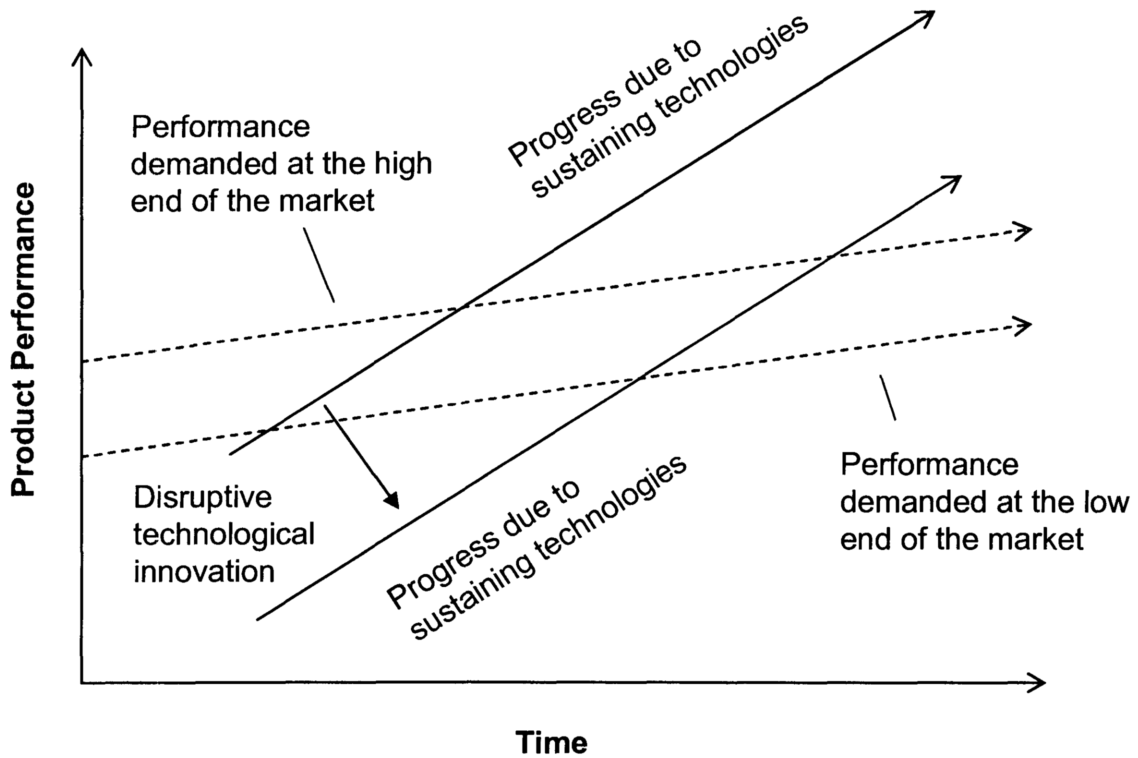

Figure 2-1 Impact of Sustaining and Disruptive Technological Change
Source: Christensen, C. M., *The Innovator's Dilemma*, Harper Business Essentials, 2000, pp. xix

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[5] Ibid., p. xv.
[6] Ibid., p. xix.

Many leading firms have difficulty in investing adequate resources in the disruptive technological innovation, because the investment provides lower margin opportunities and because their customers don't want the innovation. However, once the disruptive technology catches up with the market demand, customers really want it and it is too late for the company to adopt the disruptive technology.[7]

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[7] Christensen, C. M., *The Innovator's Dilemma*, Harper Business Essentials, 2003, p. xxiii.

2.1.3. New-market Disruption

Christensen extends his idea of disruptive technology to add another dimension to Figure 2-1 (See Figure 2-2). The third dimension represents new contexts of consumption and competition, which are new value networks.[8]

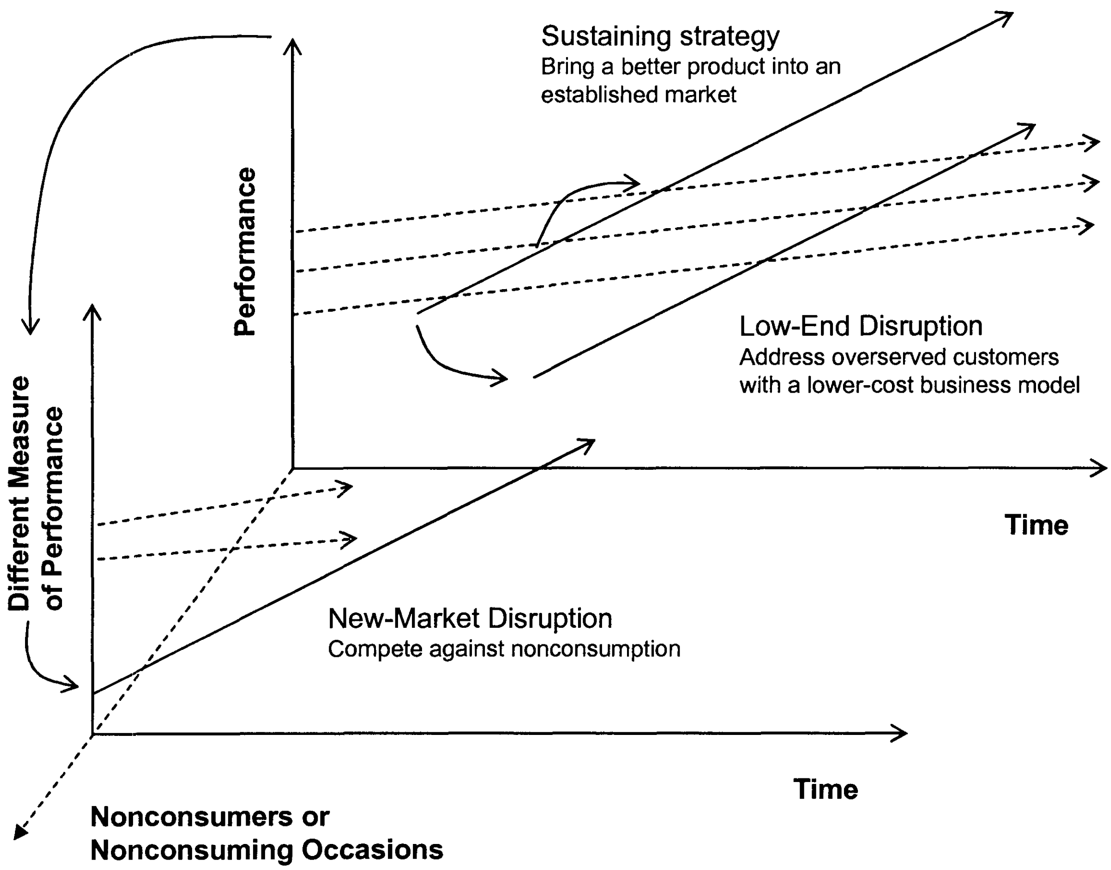

Figure 2-2 Third Dimension of the Disruptive Innovation Model

Source: Christensen, C. M., *The Innovator's Solution*, Harvard Business School Press, 2003, p. 44.

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[8] Christensen, C. M., *The Innovator's Solution*, Harvard Business School Press, 2003, p. 44.

The new value networks are generated by improvements in simplicity, portability, and product cost, and consist of new customers, who have at least one of the following factors.[9]

1. Customers who previously lacked the money to buy a conventional product
2. Customers who previously didn't have skills to buy and use the product
3. Customers who is in different situations in which a product can be used

The new-market disruptions compete with "nonconsumption" because new-market disruptive products are so much more affordable to own and simpler to use that most people can own and use the product. This disruptive innovation doesn't invade the mainstream markets, but it pulls customers out of the mainstream value network into the new one because these customers find it more convenient to use the new product.[10]

2.2. Acee's definition

Happy J. Acee questioned Christensen's definition of disruptive technologies and redefined sustaining technology and disruptive technology. Acee's sustaining technology is the technology that supports the current technology paradigm and trajectory (in the case of an assembled product), or production process (in the case of a non-assembled product). His disruptive technology is the emerging technology that deviates from the existing technology paradigm that supports an incumbent product and results in the replacement of

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[9] Christensen, C. M., *The Innovator's Solution*, Harvard Business School Press, 2003, pp. 44-45.
[10] Ibid., pp. 45-46.

the incumbent product by a new product that offers greater value.[11] He also expanded the concept of the disruptive technology as follows.[12]

1. It may be recognized by a change in the dominant design of an incumbent product, or in the dominant production process in the case of a non-assembled product.
2. It may be exploited by new entrants giving them a product-centric competitive advantage over incumbent firm.
3. Product-centric competitive advantage given by new entrants may result in the incumbent firms exiting the business.
4. It may render a majority of the value chain of all firms within an industry obsolete, resulting in the demise of the incumbent industry.

He mentioned that the result simply can't be confined to the displacement of incumbent firms by new entrants.[13]

2.3. Diagram of disruptive technologies

2.3.1. Positioning of Christensen's and Acee's disruptive technologies

As the last sentence of 2.2 shows, Acee's disruptive technology is not company-centric like Christensen's one. Because he cared more about the dominant design, production process and product-centric competitive advantage, Acee focused more on product disruption than company disruption. I show the positioning of both Christensen's and Acee's disruptive

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[11] Acee, H. J., "Disruptive Technologies: An Expanded View", SM Thesis, Management of Technology, Massachusetts Institute of Technology, 2001, p. 16.
[12] Ibid., pp. 16-17.
[13] Ibid., p. 17.

technologies in Figure 2-3 in which I called Christensen's and Acee's disruptive technologies "Company" and "Product" disruptive technologies respectively.

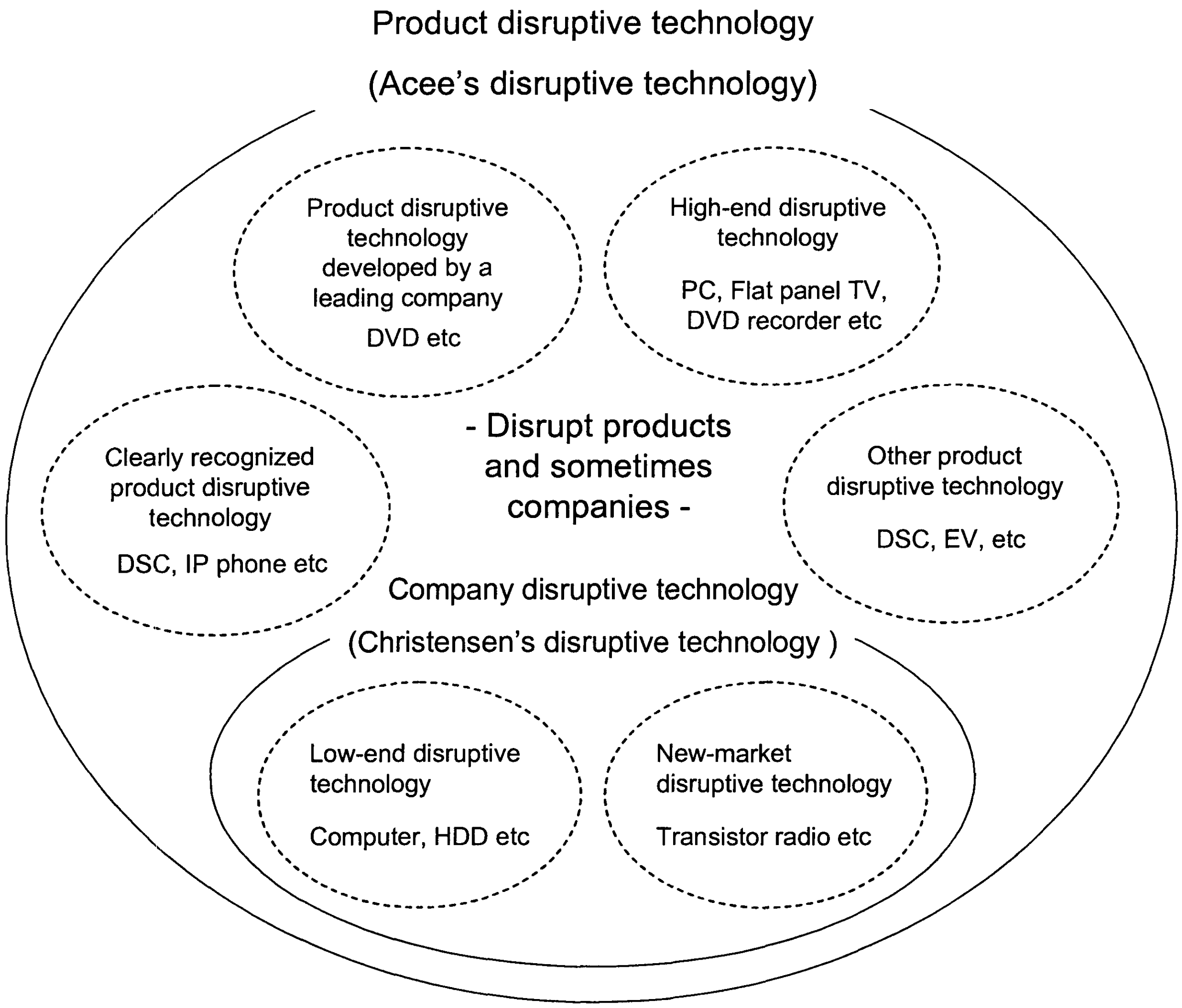

Figure 2-3 Positioning of both Christensen's and Acee's disruptive technologies

The company disruptive technology always kills both incumbent companies and incumbent products under well-defined and narrowly limited conditions. On the other hand, the product disruptive technology disrupts incumbent products and isn't directly related to bankruptcy of companies. Companies might be disrupted because of the fatal damage caused by the product disruption; however, the company disruption is not a necessary condition for the product disruption.

The disruptive technologies circled by a broken line are some of examples positioned outside the definition of the company disruptive technology within the definition of the product disruptive technology.

2.4. Low-end and high-end disruptive technologies

2.4.1. Advantage in the market for each technology

Where does the disruptive technology come from? Christensen mentioned that the disruptive technology comes from a low-end market.[14] This is one of the possibilities. However, there seems to be many disruptive technologies which are more expensive than corresponding incumbent technologies when they are first launched. First, I shall discuss the low-end disruption in order to resolve this contradiction. As shown in "The Innovator's Solution", the incumbent company runs away to a upper market when the disruptive technology attacks it from the lower market,[15] because the disruptive technology, which comes from the low-end market, has more advantage in cost than the incumbent technology has; that is, the incumbent technology avoids competing in cost with the disruptive technology and move to the market where it has more advantage, such as in performance, than the disruptive technology has. Through this process, the

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[14] Christensen, C. M., *The Innovator's Solution*, Harvard Business School Press, 2003, p. 46.
[15] Ibid., p. 46.

decision-making pattern pushes the incumbent company to move to the upper market because this pattern has also been established in performance-centric environment compared to the environment of the disruptive technology.

However, cost is one of the value criteria for a customer. Customers decide which product they purchase from the many different points of view. I show the customer's value criteria by the following equation, using representative factors of customer value.

$$V = C(c) + P(p) + A(a) + O(o) \tag{2-1}$$

Here $C(c)$ is the function of cost, $P(p)$ is that of performance, $A(a)$ is that of availability, and $O(o)$ is the combined function of other possible factors. On condition that the availability and other factors are constant, for example we can use both incumbent and disruptive technologies freely, we can obtain equation (2-2).

$$dV = \left(\frac{\partial V}{\partial c}\right)_{p,a} dc + \left(\frac{\partial V}{\partial p}\right)_{c,a} dp \tag{2-2}$$

The low-end disruption takes into account the cost effect on the customer value. The sensitivity to the cost coefficient, $\left(\frac{\partial V}{\partial c}\right)_{p,a}$, is very high in the low-end market. The low-end disruptive technology attacks the incumbent company in an area where it can take advantage of the low cost. It then improves its weak point - performance - during its successful duration in the low-end market. Once it reaches the performance level which it can compete with incumbent technology at the next upper market, the low-end disruptive technology starts to disrupt the incumbent one at the upper market.

Let me discuss the case that the disruptive technology has the advantage of performance. The disruptive technology comes from the upper-end market in this case, because it needs to compete with the incumbent technology in terms of performance and because the sensitivity to performance is high in the upper market. While it enjoys success in the upper market, the disruptive technology can be improved in its weak point - cost - through sustaining innovations and economies of scale. When the disruptive technology comes from the upper market, the incumbent company runs away to the lower market, because the strength of the incumbent technology against the disruptive one is cost (sometimes cost and simplicity). Thus, the incumbent company tries to survive or compete in a market where it can take advantage of its own strong point. I show the high-end disruptive technology as a framework in Figure 2-4.

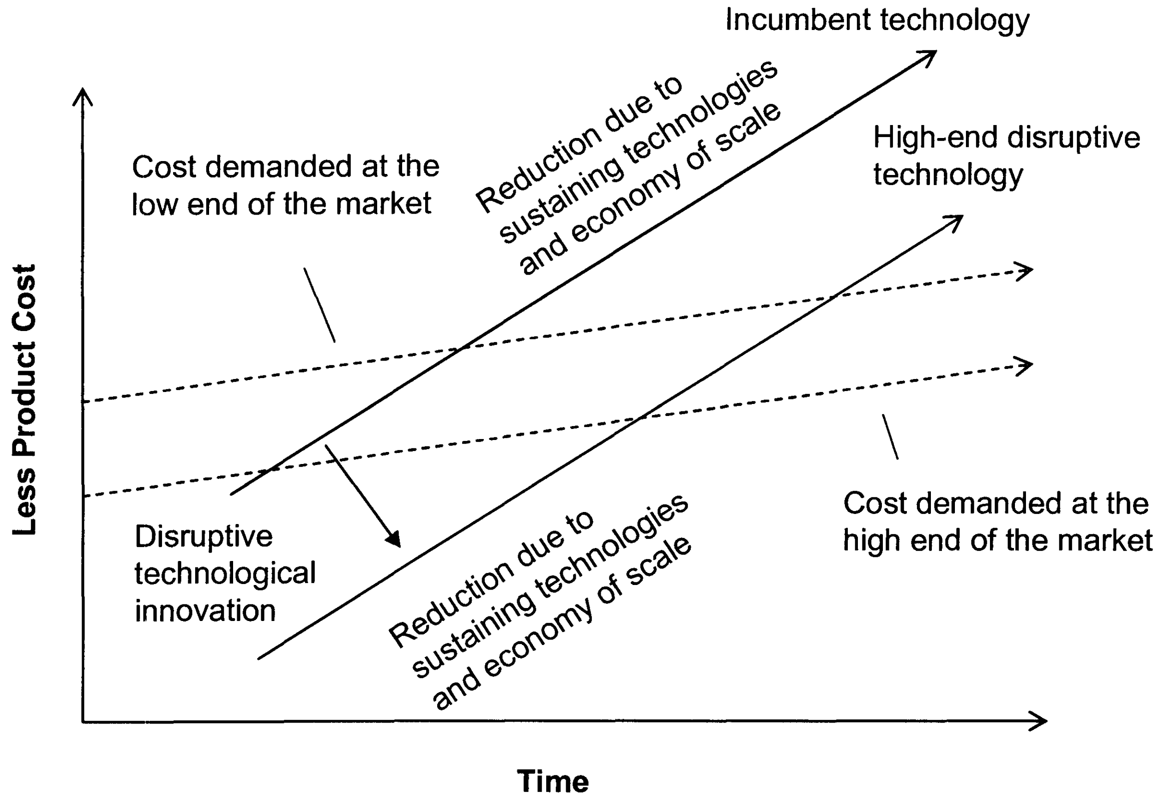

Figure 2-4 High-end disruptive technology

I will show some examples of the high-end disruptive technology in the following section.

2.4.2. A case: PCs and word processors

When the PC appeared in the market, it was so expensive that people could not purchase PC and still used word processors instead of PCs. However, the price of PC decreased rapidly thanks to sustaining innovation, economies of scale, the disruptive innovation of channel and so on, and pretty soon people started to purchase PCs.

James M. Utterback mentioned about the disruptive innovation caused by PCs in his book "Mastering the Dynamics of Innovation".[16] We can't say that the PC was superior in performance to the word processor when it was introduced into the market. However, the performance of the PC had been improved by the sustaining innovation and exceeded that of the word processor quickly. Once its performance became high enough, it started to function as the high-end disruptive product. According to Utterback, many company exited the industry due to this high-end product disruption in 1983; Commodore, Atari, and Texas Instruments experienced serious business problem; Timex-Sinclair, Osborne, Coleco, and Mattel vanished from the industry.[17]

Thanks to unique characteristics of Japanese language, a Japanese language word processor could survive longer than its US counterpart. The Japanese language word processor was developed by Toshiba Corporation. Toshiba launched JW-10 (see Figure 2-5) at 6,300,000 yen in 1978, and then decreased the price dramatically through sustaining innovation; for example, JW-10-2 was sold at 4,900,000 yen and JW-5 was sold at 2,600,000 yen. In July of 1985, Toshiba launched the RUPO-10 portable model (JW-R10; see Figure 2-5) at 99,800 yen.[18]

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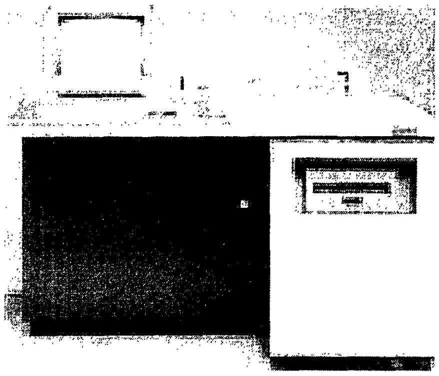
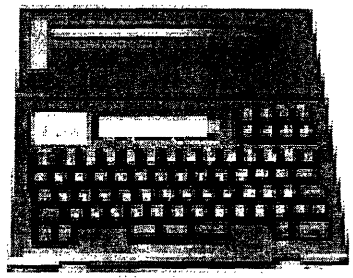
[16] Utterback, J. M., *Mastering the Dynamics of Innovation*, Harvard Business School Press, 1996, pp. 14-17.
[17] Ibid., p. 17.
[18] Abetti, P. A., "The birth and growth of the Japanese language word processor: internal venturing in Toshiba Corporation", *Int. J. Technology Management*, Vol. 18 Nos. 1/2, 1999, p. 124.





JW-R10

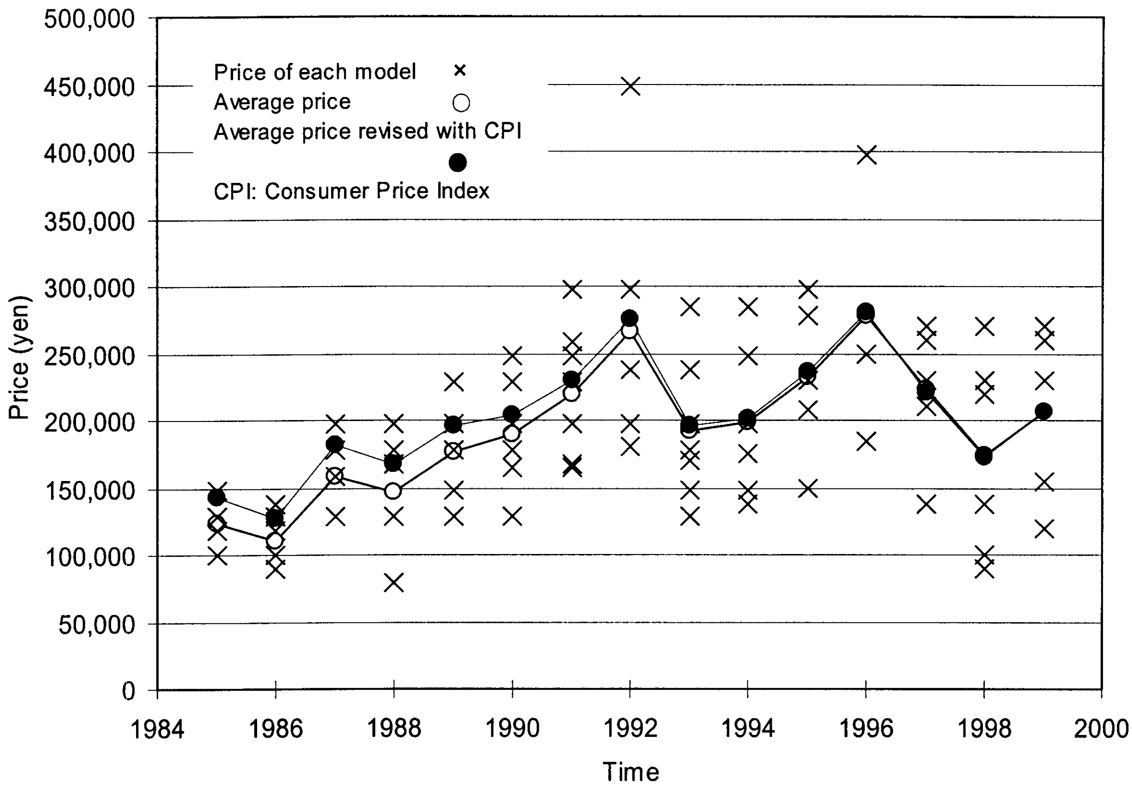
JW-10

Figure 2-5 JW-10 and JW-R10

Source: http://www.toshiba.co.jp/kakan/history/1goki/1978wordpro.html

In 1985, the price of the PC was much more expensive than that of the word processor; thus, word processor manufacturers could enjoy their success and further improved the performance of word processors through sustaining technologies. Since many functions, such as the wide display and several font sets, were added, the average price of RUPO models became 267,000 yen in 1992.[19] Figure 2-6 shows the price trend of RUPOs.

[19] http://www.toshiba.co.jp/rupo/history/index_j.htm



Note: open prices (1995-1997) are not included in the graph

Figure 2-6 Price trend of RUPOs

Source: http://www.toshiba.co.jp/rupo/history/index_j.htm

http://www.stat.go.jp/english/index.htm

During this successful period for word processors, the price of PC was reduced by sustaining technologies. In the early 1990s, the price of a PC with a Japanese word processor software became less than 300,000 yen and started to compete severely with the word processor, as shown in Figure 2-7.[20][21]

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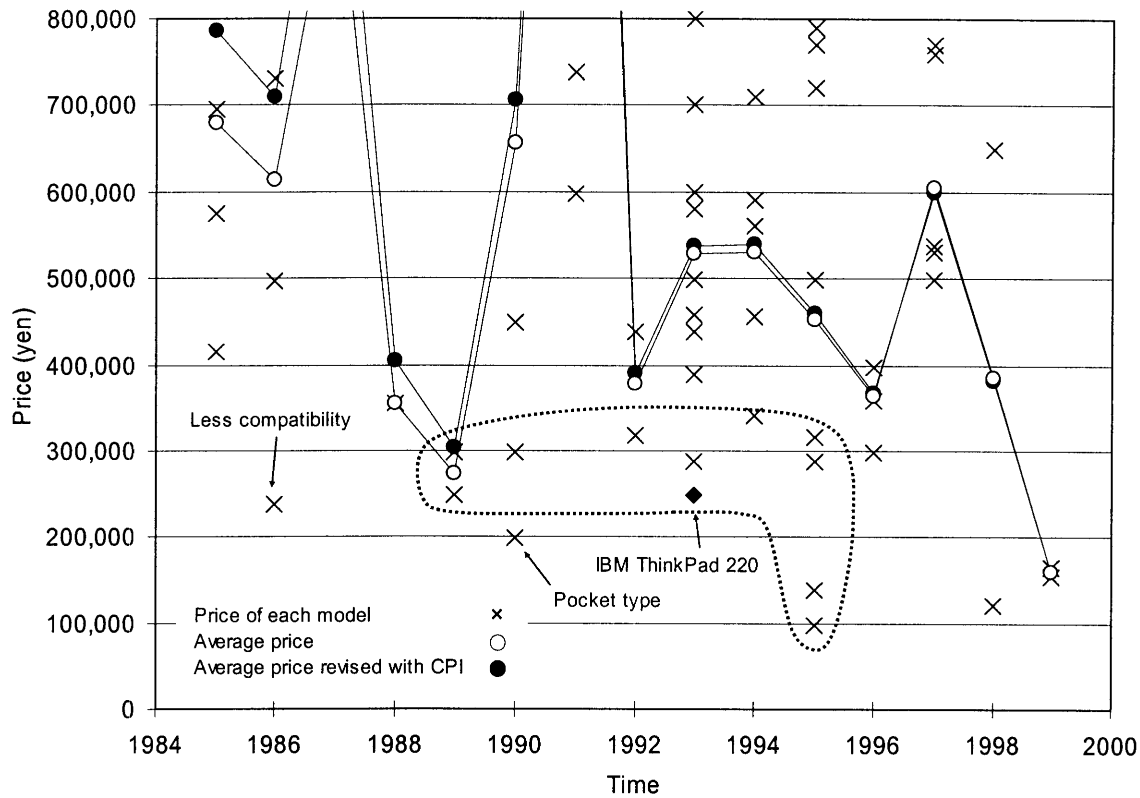
[20] http://www-6.ibm.com/jp/domino05/ewm/NewsDB.nsf/1993/09274

[21] http://121ware.com/community/navigate/communication/pcmuseum/index



Note: open prices (1998-1999) are not included in the graph.

data includes the PC price without the Japanese word processor software.

Figure 2-7 Price trend of Japanese PCs (NEC Corporation)

Source: http://www-6.ibm.com/jp/domino05/ewm/NewsDB.nsf/1993/09274

http://121ware.com/community/navigate/communication/pcmuseum/index

http://www.stat.go.jp/english/index.htm

Thus, the trend of price increase of the word processor changed around the middle of 1990s and started to decrease at the later 1990s. In 2000, Toshiba decided to withdraw its word processor business and many word processor manufacturers, such as NEC, Fujitsu, and Sharp, followed in 2001 and 2002. The peak of production of the Japanese language word processor was 2.71 million sets in 1989, but dropped to 750 thousand sets, which was 40% less compared to the previous year, in 1999.[22] The word processor disappeared soon after it started to compete with the PC, so we can't clearly find that the incumbent company ran away into the lower market. On the contrary, there were some attempts to compete with the PC in performance. We can easily find that high-end models of the word processor were still being brought to the market during the severe competition with the PC in Figure 2-6. According to Kenichi Mori, the inventor of the Japanese language word processor, Toshiba had to decide which value criteria its word processor should use to compete with the PC, cost or performance.[23] Someone insisted that the word processor should compete with the PC in performance, adhering to past successful experience gained by adding functions despite price increases. Eventually, Toshiba decided to make its word processor compete in performance; however, I believe that this challenge ironically shortened the product life of the word processor. I think that another reason the word processor was disrupted so quickly is as follows. Most of the Japanese language word processor manufacturers produced both the PC and the word processor, so it was comparatively easy for them to transfer their resource to the new business. Unlike the low-end disruption, the disruptive technology erodes the most profitable market, so the company notices the damage quickly and this sometimes helps the company to decide to withdraw from the business expeditiously.

Mori commented on the reason for the withdrawal at an interview with Yasuyuki Asada,

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[22] http://www.sankei.co.jp/databox/pc/0006html/22kei009.htm
[23] Interview with Dr. Mori on March 29, 2004.

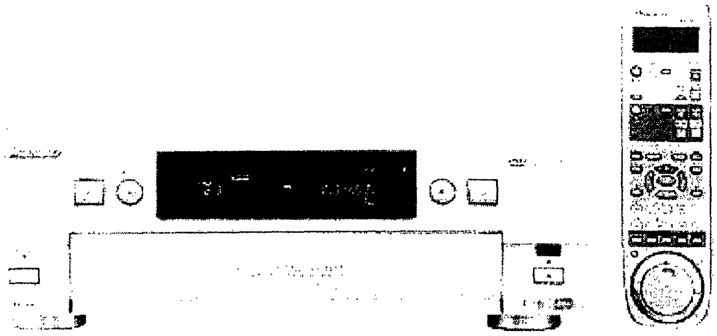
the president of Toshiba science museum.[24] He replied to Asada, "The reason Toshiba withdrew the word processor business is very clear. Since Toshiba targeted less than 100,000 yen for the RUPO portable model in order to make it popular for home use, the RUPO-10 portable model was sold at 98,000 yen. However, it exceeded 200,000 yen because Toshiba continued to add various functions and increased its price. Then, the PC price started to decrease to the same as that of the word processor, and then customers supported the PC. Thus I am planning to develop the simple word processor which focuses on the function to write......." I think that his plan can be the example of the behavior of an incumbent company during a high-end disruption. The incumbent technology can compete with the disruptive technology in cost and simplicity in the high-end disruption. I can't predict how long the simple word processor's life cycle is, but I believe that it can survive until the PC attacks on the basis of cost. It can also survive in a niche market evaluated by a different value criteria (I will discuss the customer value criteria in chapters 4 and 5).

2.4.3. A case: DVD recorders with HDD and VCRs

A DVD recorder with HDD is popular only in Japan so far, but has the huge potential to be the high-end disruptive technology for a VCR. Thus, we focus on only the Japan market of these products. The DVD recorder has two de facto standards, DVD-RW and DVD-RAM. Pioneer launched DVR-1000, a DVD recorder of DVD-RW, at 250,000 yen in December of 1999 and Toshiba launched RD-2000, that of DVD-RAM, at 270,000 yen

[24] http://www.toshiba.co.jp/kakan/community/interview/iv05/

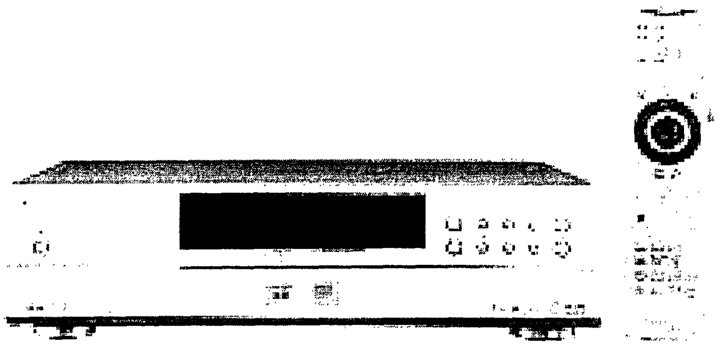
in December of 2000 (see Figure 2-7).[25][26]



Price: 250,000 yen

Function: quick and easy recording, optimum picture quality with manual rate recording, disc navigator for instant index viewing, variety of editing functions, disc program recording system

DVR-1000



Price: 270,000 yen

Function: maximum 33.5 hours recording, HDD-based viewing functions, library functions, easy recording and search function, high quality picture and sound recording, adaptable for various image sources

DR-2000

Figure 2-7 DVR-1000 and DR-2000

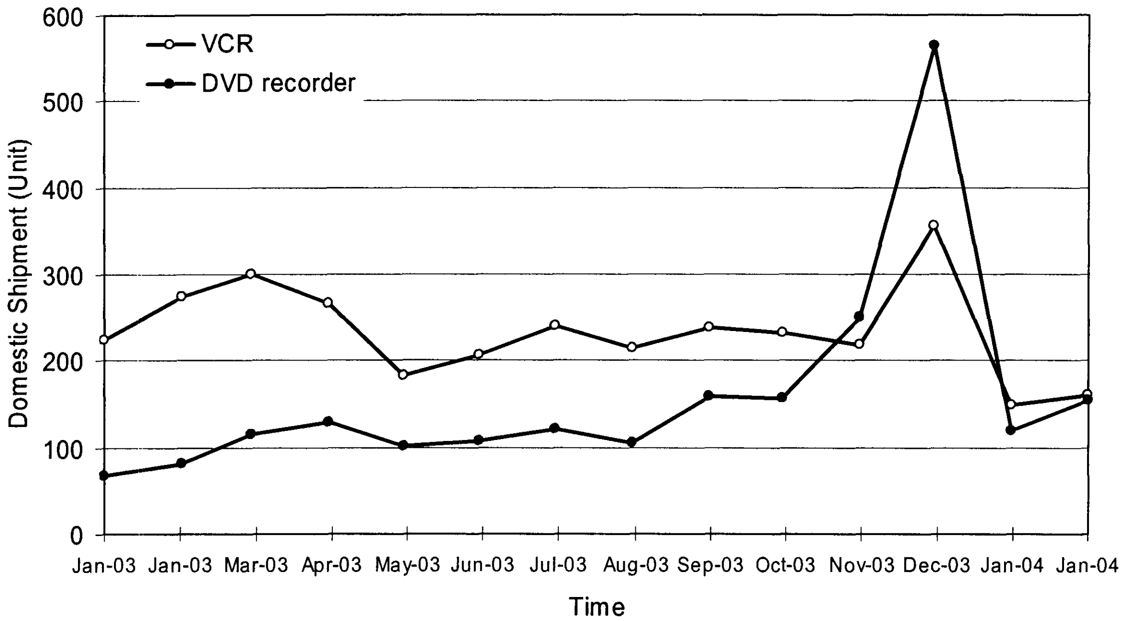
Source: http://www.pioneer.co.jp/press/release63.html

http://www.toshiba.co.jp/about/press/2000_11/pr1601.htm

These first DVD recorders were much more expensive than the VCR and their recording

[25] http://www.pioneer.co.jp/press/release63.html
[26] http://www.toshiba.co.jp/about/press/2000_11/pr1601.htm

quality was not higher than that of the VCRs. In addition, people hesitated to purchase the DVD recorder because of existence of two de facto standards. Thus, the DVD recorder could not sell well for some time. However, its performance has been improved by sustaining technologies and its cost has also been reduced by both sustaining technologies and economies of scale. The DVD recorder started to be popular in the late 2002 and exceeded the VCR in November of 2003 (see Figure 2-8).[27]



Note: December is traditionally big-sales month in Japan.

Figure 2-8 Shipments in Japan of DVD recorders and VCRs

Source: http://www.jeita.or.jp/english/stat/index.htm

Although the price of DVD recorders decreased, it was still more expensive than a

[27] http://www.jeita.or.jp/english/stat/index.htm

high-end VCR. However, higher performance, such as time-shift playback and editing capability through a PC, attracted the customer who wanted to enjoy its excellent performance even though he or she already possessed the VCR. This high-end disruptive technology created a new market for the person who could not purchase the product because of the non-existence of the product. This is somewhat similar to the new-market disruption of Christensen; however, users of VCRs or DVD recorders did not increase even though total sales of DVD recorders and VCRs increased. (Both the number of users and total sales increase in new-market disruption.) Although DVD recorders are still expensive, we can expect that the price of DVD recorders will continue to decrease and that it will start to compete directly with the VCR in the high-end market of the VCR.

2.4.4. Other examples

Several flat panel displays have challenged to become the disruptive technology against CRTs. Each technology has pros and cons compared to the CRT technology. For example, the LCD still has disadvantages in the viewing angle, response speed, and brightness control, and the Plasma Display Panel (PDP) has those in power consumption and brightness.[28] However, many customers regard both flat panel displays highly because of their thickness and weight. Customers decide which product they purchase from many points of view. Thus, we can say that total value in performance for customers of the flat panel display is higher than that of the CRT. The flat panel display is still more expensive than the CRT, but it has already started to penetrate the upper

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[28] Nikkei Micro Device, *Flat panel display 2004*, Nikkei Business Publications, Inc., 2004, p. 43.

market of the CRT thanks to its high performance. Now many manufacturers are reducing its production cost. Sharp Corporation is planning to reduce the cost by choosing the appropriate size of a mother glass board, materials, and processes; Samsung Electronics Co., Ltd. and LG. Philips LCD Co., Ltd. will do so by enlarging the size of the mother glass board, for example by introducing 7th generation (1500x1850mm^2).[29] Figures 2-9 and 10 show the shipments of the CRT, the LCD, and the PDP in Japan, where the market has low sensitivity to cost compared to other markets.

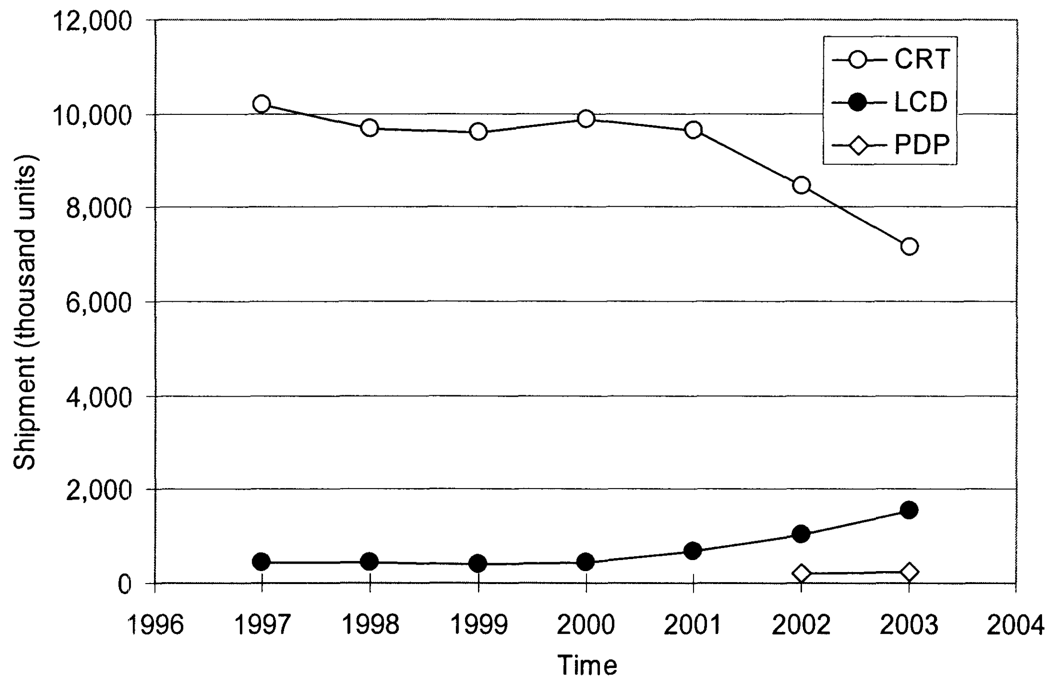

Figure 2-9 Shipments of displays in Japan market

Source: http://www.jeita.or.jp/english/stat/index.htm

[29] Ibid., pp. 50-51.

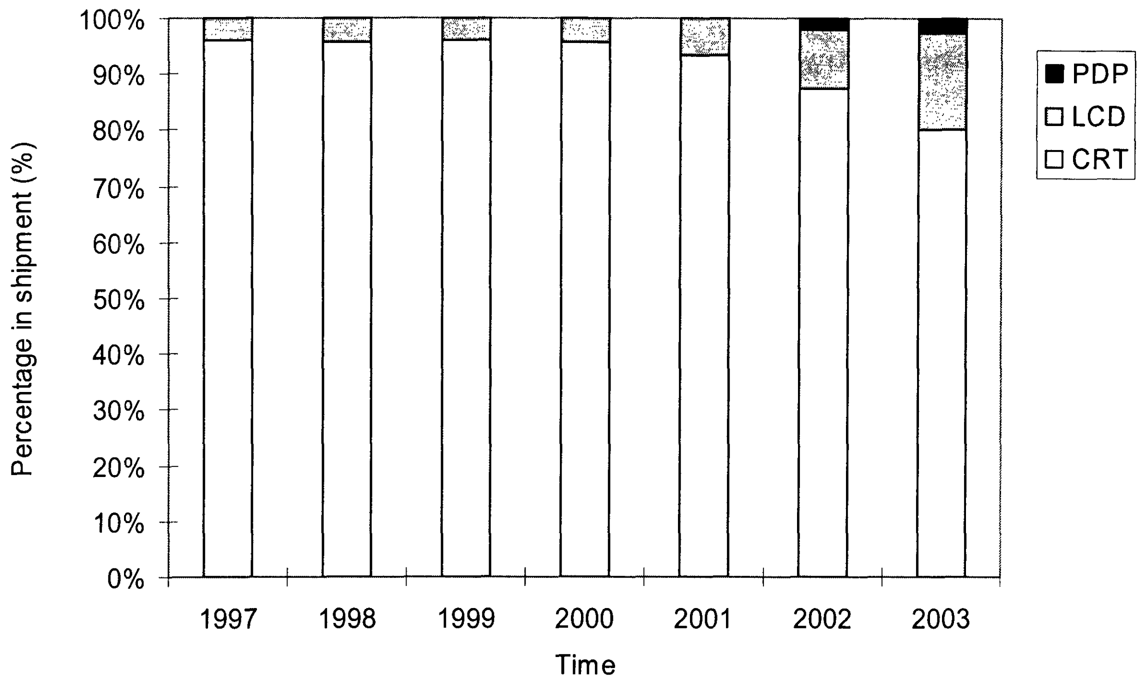

Figure 2-10 Percentages of each flat panel display in shipment

Source: http://www.jeita.or.jp/english/stat/index.htm

We can find that the percentage of flat panel displays (LCD and PDP) in shipment is increasing in Figure 2-10. They attack the upper market of the CRT and have been disrupting the CRT from the upper market.

A Moving Picture Experts Group (MPEG) player is another example we can consider as the potential high-end disruptive product. The MPEG player might disrupt a Cassette Walkman. (A Minidisk Walkman already disrupted the Cassette Walkman in Japan, so the MPEG player might disrupt the Minidisk Walkman there.)

2.5. Clearly recognized product disruptive technology

When we consider time in addition to cost, performance, and availability, we can observe a different aspect of disruptive technology. Some emerging technologies need a long time to succeed. For example, the Charge Coupled Devices (CCD) technology for a camera took about 15 years to become popular. The incubation period makes it possible for the incumbent company to prepare against the disruptive technology.

In 1981, Sony Corporation developed the prototype of Mavica (see Figure 2-11), the first magnetic recording still camera in the world.[30] It was a prototype; however, the photo system of Mavica was quite impressive because it was very different from that of the conventional film camera in that CCD and the magnetic disk were applied to the system. Thus, many companies started or strengthened their research and development of the technology. For example, Canon Inc. formed a task force to develop a magnetic recording color still camera in October of 1981.[31] In 1986, Canon launched RC-701 (see Figure 2-12), the first electronic still camera to be launched in the world, and Fujifilm Photo Film Co., Ltd. developed FUJIX DS-1P, the first digital still camera (DSC), which adopted a semiconductor as a memory, in 1988 (see Figure 2-13).[32] Around 1997, DSC started to be explosively popular thanks to its sharp price fall, spread of the PC, and improvement of image processing software.[33]

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[30] http://www.jcii-cameramuseum.jp/events/20001024.htm

[31] http://www.canon.com/camera-museum/history/canon_story/1976_1986/1976_1986_story.html

[32] http://www.fujifilm.co.jp/corporate/adgallery/pdf/fujifilm_ad_001.pdf

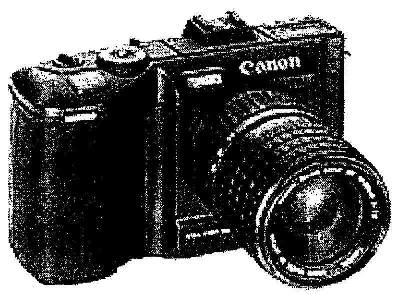
[33] http://www.jcii-cameramuseum.jp/events/20001024.htm

Announced: August 1981 (a prototype)

Function: image-recording on two-inch floppy disks, playback on a TV set or Video monitor, three bayonet-mounted lenses: a 25mm f/2, a 50mm f/1.4, and 16-65mm f/1.4 zoom, 570 x 490 pixels, shutter speed of 1/60th second, and multiple exposure of 2, 4, 8. or 20 images.

Figure 2-11 Mavica of Sony Corporation

Source: http://www.digicamhistory.com/1980_1983.html



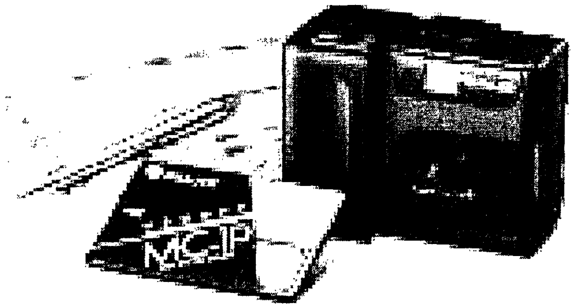
Marketed: July 1986

Original Price: 390,000 yen

Function: 780 pixels (horizontal), image-recording on a special floppy disk standardized by the industry, a 10 fps (frames per second) high-speed shutter-priority, multi-program automatic exposure, and LCD panel for exposure data and camera information.

Figure 2-12 RC-701 of Canon Inc.

Source: http://www.canon.com/camera-museum/camera/sv/index.html



Marketed: September 1988

Function: digital recording on memory cards, 400K CCD, fixed-focus, 16mm f/5.6 (f/4 with flash) lens, and shutter speed of 1/60 to 1/2000 second.

Figure 2-13 FUJIX DS-P1 of Fujifilm

Source: http://www.digicamhistory.com/1980_1983.html

http://www.fujifilm.co.jp/corporate/adgallery/pdf/fujifilm_ad_001.pdf

The world share of DSC is shown in Figure 2-14. We can find that most of the top manufacturers are incumbent companies.

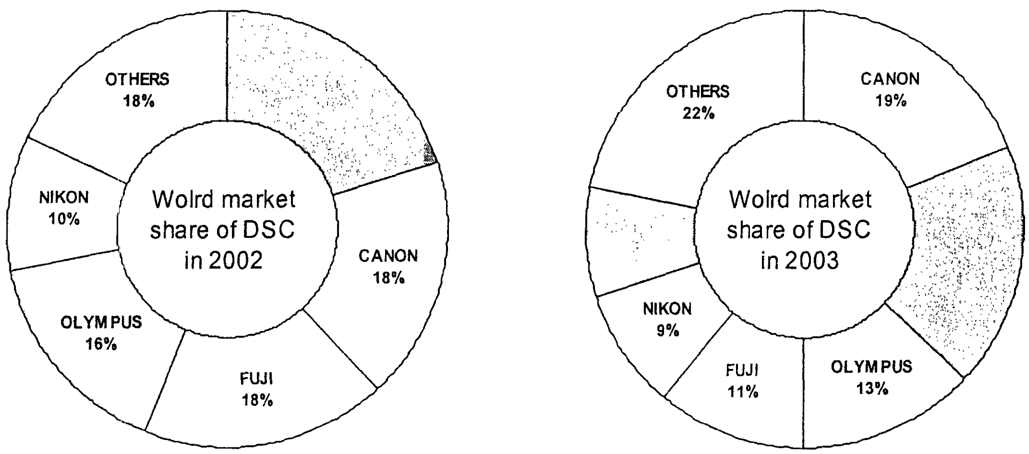


Figure 2-14 World market share of DSC

Source: Development Bank of Japan, "Gendai Nihon Sangyo Ron Dai 5kai", October 28, 2003

Okasan Securities Co., Ltd., "Tokusyu Dejitaru Kaden", February 3, 2004

Why could these incumbent companies grow the disruptive business in their business portfolio? One reason is that the optical technology was still required in production of DSC. However, we can find an interesting answer if we see the annual report of Sanyo Electric Co., Ltd. According to the 2003 annual report, Sanyo produced 3.3 million units of DSC in 2000, 4.5 million in 2001, and 6 million in 2002.[34] This means Sanyo occupied from 20 to 30 % of world production share. Satoshi Iue, Chairman & Chief Executive Officer of Sanyo, mentioned in the interview with Nihon Keizai Shimbun,Inc. that Sanyo made use of its strength in original equipment manufacturing (OEM) in the DSC business. Sanyo provided about 5 major Japanese DSC companies with OEM products.[35] Some incumbent companies have utilized Sanyo, an electric company, in order to survive in the disruptive business. Thanks to the modular structure of DSC, the incumbent company also utilized electric company's technologies by purchasing LSIs. Some incumbent companies bought technologies, or jointly developed new technologies with electric companies. Pentax Corporation and Casio Computer Co. Ltd. jointly developed new technologies and brought Optio S and Exilim EX-Z3 into the market respectively. According to the announcement for the press in Tokyo on February 4, 2003, Pentax provided the sliding lens system, which made lens compact by sliding middle 3 lenses to the upper part of the camera, for Casio. On the other hand, Casio provided Pentax with Stack MCM (MCM; Multi Chip Module) for the image processing circuit.[36]

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[34] Sanyo Electric Co., Ltd., "Annual report 2003 (Japanese version)", June, 2003, (only Japanese version mentioned this), p. 3.

[35] "Sanyo Dejikame 7wari Zoukyou", *Nihon Keizai Shimbun*, December 13, 2003

[36] http://pc.watch.impress.co.jp/docs/2003/0204/pentax.htm

The incumbent company could prepare against the disruptive technology thanks to the incubation period. One option was to obtain human resources from electronic companies. An incumbent company chose this option and developed its own technology internally. When it developed the disruptive technology internally, the separate organization worked well as Christensen mentioned.[37]

(I can't judge whether the new organization could succeed or not if it worked under mainstream processes and values, but at least the independence from the main organization buffered it from the mainstream pressures. The company allocated the required resources separately from the mainstream organization by obtaining it from electrical companies.)

According to a manager of the incumbent company, they noticed that this emerging technology was the technology which had a possibility to disrupt the conventional camera although there was no academic concept of the disruptive technology at that time.[38] They were strongly impacted by Mavica of Sony Corporation, which called "Mavica shock" in Japan, and started to research and develop CCD internally. When they started businesses related to electronics, such as Digital Video Movie, the company needed human resources from outside because its technological strength was in analog and chemical technologies. Thus, they headhunted the top management and engineers from electrical companies. They developed the technology for DSC by themselves and didn't outsource technology

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[37] Christensen, C. M., *The Innovator's Dilemma*, Harper Business Essentials, 2003, pp. 202-207.

[38] Interview with a manager of the incumbent camera manufacturer on March 17, 2004

matters. They thought that the core technology, such as CCD, should be developed internally because the film camera would be disrupted in future. The research group of CCD was separated from that of the film camera; this separation prevented the organization from spending too much effort to fight against the severe pressures from the mainstream business. Thanks to this decision, it could successfully grow the disruptive technology internally although it was one of the leading film camera companies. In early 1990s many electronic companies entered the DSC market and started to attack the conventional market, but the conventional camera companies rallied quickly because they knew how to produce excellent cameras thanks to their rich experience. This incumbent company adopted the disruptive technology by internal development and some incumbent companies conquered the digital technology thanks to the modular structure of DSC and the high leverage provided by their traditional strengths such as optical technologies. I strongly believe that the incubation period of the disruptive technology enabled the incumbent company to prepare for the disruption.

Internet Protocol (IP) phone is another example of the clearly recognized product disruptive technology, which might seriously impact the existing value network. (I will discuss value network in Chapter 3.) Incumbent companies, such as AT&T Corp. and Nippon Telegraph and Telephone Corporation (NTT), started to prepare against the disruptive technology. For example, NTT and NTT Communications (NTT Com) subscribed for shares of common stock of Internet Initiative Japan Inc. (IIJ), which has strong skills on IP telephony, by third party allotment.[39][40] Kawashima showed the strategy for IP telephony from the viewpoint of the incumbent company in his research.[41]

2.6. Product disruptive technology developed by a leading company

We can find some cases of product disruptive technology developed by a leading company. Christensen mentioned that the development of the disruptive technology is often the work of engineers at established firms with bootlegged resource although entrants led in commercializing the technology.[42] In fact, the DVD was developed by Toshiba (the incumbent company of the VCR), standardized in specification in December of 1995[43][44], and then launched by Toshiba and Matsushita Electric Industrial Co., Ltd., which was also a leading company of the VCR, in November of 1996.[45]

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[39] http://www.ntt.co.jp/news/news03e/0309/030916.html

[40] http://www.iij.ad.jp/en/pressrelease/2003/0916.html

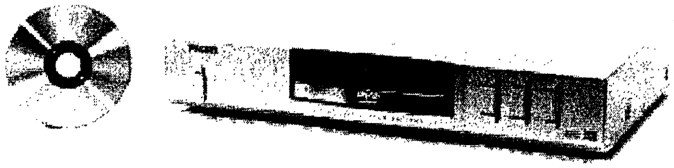
[41] Kawashima, M., "Telecom Value Chain Dynamics and Carriers' Strategies in Converged Networks", SM Thesis, Management of Technology, Massachusetts Institute of Technology, 2002

[42] Christensen, C. M., *The Innovator's Dilemma*, Harper Business Essentials, 2003, p. 49.

[43] http://www.toshiba.co.jp/about/press/1995_02/pr2702.htm

[44] http://www.toshiba.co.jp/about/press/1995_12/pr_j0801.htm

[45] http://www.toshiba.co.jp/about/press/1996_09/pr2603.htm



Marketed: November 1996
Price: 77,000 yen
Feature: a highly-reliable, switchable dual-lens pick-up, multilingual capabilities, multi-aspect, multi-angle viewing, and multi-story function, many playback functions, and Dolby Digital (AC-3) decoder

Figure 2-14 SD-3000 of Toshiba

Source: http://www.toshiba.co.jp/about/press/1996_09/pr2603.htm

Why could Toshiba and Matsushita be the world's first to commercialize the DVD even though they were the large venders of the VCR? According to Kenichi Mori, the former executive of Toshiba, the VCR business did not affect Toshiba's decision to launch the DVD business at all.[46] The DVD business started when Toshiba created the new concept for the next-generation audiovisual application and proposed joint development to Time Warner Inc. in 1990. Toshiba already found that the VCR could not satisfy the quality requirement from Hollywood in terms of picture and sound, so it thought that VCRs would disappear in future. Thus, Toshiba ignored the fact that it ran the VCR business when it made the business strategy of DVD. It also considered the possibility of DVD not only as audiovisual media but also storage device for personal IT equipment such as the PC, so it surveyed the demands from computer companies and decided the business strategy (see

[46] Interview with Dr. Mori on March 29, 2004.

Table 2-1).

Requests from the Hallywood	Requests from the computer industry
• Higher quality of pictures and sounds than conventional devices	• Same specification of AV and PC
• Recording time more than 133 minutes	• Compatibility with the conventional CD
• Dolby Digital 5.1ch, multi-sround sound	• Compatibility with the common file system
• Multi-caption, multi-lingule	• Capability to have the large capacity in future
• Same production cost as the CD	• Random acess
• Protection of the copyright	• Low cost
• Other function such as interactive function	• Caddyless

Table 2-1 Requests from the industries

Source: http://panasonic.jp/p3/dvdram/technology/dvd_world/pages/dvd_world_01.html

The incumbent company could position DVD technology as the advanced technology for the future even though it was very different from the VCR technology. The DVD technology is not classified into the low-end disruptive technology; that is, it didn't have to target the lower market where the profit margin was very low. It has less trouble to develop the disruptive technology compared to the low-end disruptive technology even though the technology is quite new for the company. It is too early to say that the DVD technology is not a disruptive technology because the leading company positions it as the advanced conventional technology. We might say that the DVD technology was the sustaining technology of the CD technology; however, it was the product disruptive technology against the VCR technology because it was originally from a completely different technology trajectory from that of the VCR and because the DVD has disrupted the VCR since it appeared.

2.7. Other product disruptive technology

So far, I have showed several examples of product disruptive technology. There are yet others. For example, DSC comes with low performance and high cost, but some functions were suitable for the niche market such as those for journalism and professionals; the price of RC-701 was 390,000yen, but about 5 million yen for the whole system.[47]

Date	Model	Price	Picture quality
July, 1986	RC-701	390,000 yen	780 pixel (horizontal)
February, 1988	RC-760	590,000 yen	600K pixel
November, 1988	RC-470	238,000 yen	360K pixel
November, 1988	RC-250	98,000 yen	786 pixel (horizontal)

Table 2-2 Prices of early DSCs of Canon

Source: http://www.canon.com/camera-museum/camera/sv/index.html

However, the DSC has improved its cost and performance through sustaining technologies, and has disrupted the film camera.

An Electric Vehicle (EV) also comes with low performance and high cost. When Toyota Corporation launched Prius, the first Hybrid Electric Vehicle (HEV) in the world, in 1997, it priced Prius very low for its production cost because it judged that the average public evaluation of the car's environment-friendly characteristics couldn't compensate for the cost increase; we will find that the public's evaluation was not so high if we consider its production cost. In addition, Japanese government wanted to popularize HEV and EV for

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[47] http://www.jcii-cameramuseum.jp/events/20001024.htm

environmental reasons, especially for the carbon dioxide emissions, so it provided a subsidy for HEV and EV based on the price difference between a conventional car and a HEV.[48] Thanks to company and government policies, Prius has been produced and improved in performance and cost through sustaining innovation. The HEV has the potential to become the disruptive product against the conventional car. The disruption will be high-end disruption if its performance exceeds that of the conventional car. This might be a case that a leading company develops product disruptive technology. We might classify it into clearly recognized disruption or new type of disruption according to how the technology disrupts the incumbent one. It seems to be difficult to classify it into a disruption category at the present moment.

2.8. Summary

There are other disruptive technologies which are different from the one that Christensen mentioned. If we define Christensen's and Acee's disruptive technologies as company and product disruptive technologies respectively, the company disruptive technology will be included in the product disruptive technology. The high-end disruptive technology is the mirror of the low-end disruptive technology of Christensen's. If we introduce the concept of the customer value criteria and treat performance and cost as same-weight variables, we will find that the low-end disruption is just a special case of the product disruption. When the incumbent company is discomfited by a newcomer with the disruptive technology, it chooses the market in which it has the upper hand over the

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[48] http://www.jari.or.jp/ja/h16_hojo/index3.html

newcomer. This is a common phenomenon shown in both low-end and high-end disruptions.

Some technologies take long time to become disruptive technologies. The incubation period of the disruptive technology allows the incumbent company to prepare against the disruptive technology. The incumbent company tries to adapt the disruptive change by means of technology alliances, headhunting, M&A, joint development and so on when it is able to recognize the emerging technology as a disruptive one. The disruptive technology might be developed by a leading company of the disrupted product. The leading company will invest and develop the disruptive technology if it understands the possibility that its mainstream product will disappear or if it positions the disruptive technology as the advanced technology of the incumbent one. I think that it also requires the idea that the market will be expanded by the technology.

The world is not so simple that we can recognize other types of disruptive technology. Some disruptive technologies come with low performance and high cost; they might find the niche market like the low-end disruptive technology. In a niche market, the customer judges product performance according to a set of criteria different from that of the mainstream market; however, the production cost of the disruptive technology is not cheaper than that of the incumbent technology.

3. Company disruption and product disruption

3.1. Company disruption follows product disruption

In chapter 2, I showed the new classification of disruptive technologies. Christensen showed the importance of understanding company disruption for successful growth in his book "The innovator's solution". He discussed the organization's capability of disruptive growth, the management of the strategy development process, the role of senior executives in leading new growth and so on.[49] According to Christensen, these factors are very useful. And yet, despite this knowledge, why are many companies disrupted or badly damaged by emerging technologies?

When we observe company disruption, we notice that the disrupted business in the disrupted company represented a whole or most of business of the company. That is, company disruption follows product disruption. The product disruption kills the business of the company and damages company performance. Whether the company disruption follows the product one depends on both the magnitude of the damage and the company's strength. On this point, we can say that a diversified business portfolio can reduce the risk of disruption for the company. In addition, the disruption does not always mean immediate extinction of the conventional market. For example, minicomputers eventually overtook the mainframe computer market, but the disruption created new net growth (See Figure 3-1).[50] IBM could survive under the disruption process of the

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[49] Christensen, C. M., *The Innovator's Dilemma*, Harper Business Essentials, 2003

[50] Gilbert, C., "The Disruption Opportunity", *MIT Sloan Management Review*, Vol. 44 Issue 4, Summer 2003, p. 32

mainframe computer thanks to its strength and the mainframe computer market growth under the disruption.

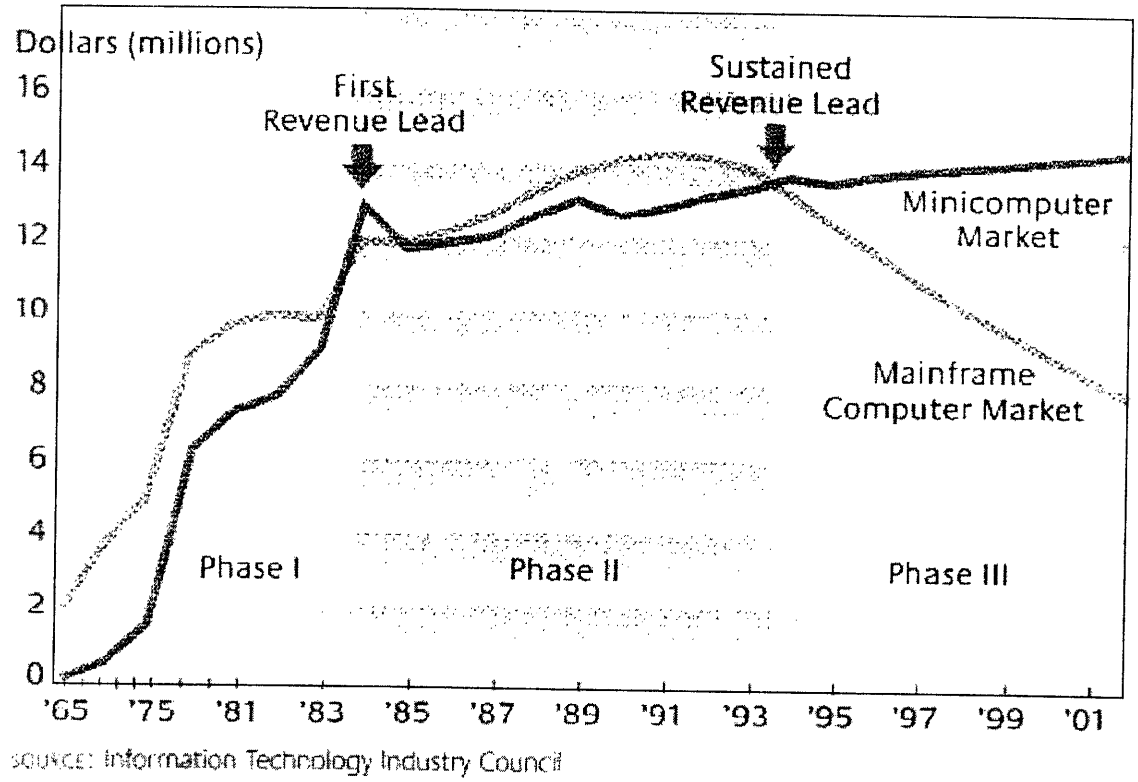

Figure 3-1 Markets of minicomputer and mainframe computer

Source: Gilbert, C., "The Disruption Opportunity",

MIT Sloan Management Review, Vol. 44 Issue 4, Summer 2003, p. 29

Targeting the company disruption is useful, but it is not enough. We can save the company by considering the product disruption. As mentioned in Chapter 2, many conventional camera companies are not disrupted so far thanks to the preparation against a recognized disruptive technology, although we can't make a final judgment whether they can survive or not because the disruption is in progress.[51] The top 5 companies (see Figure 2-14) are Japanese companies, so I show shipments in Japan of DSCs and film cameras in Figure 3-2; we can easily observe that the product disruption of film camera is progressing in Figure 3-2.[52]

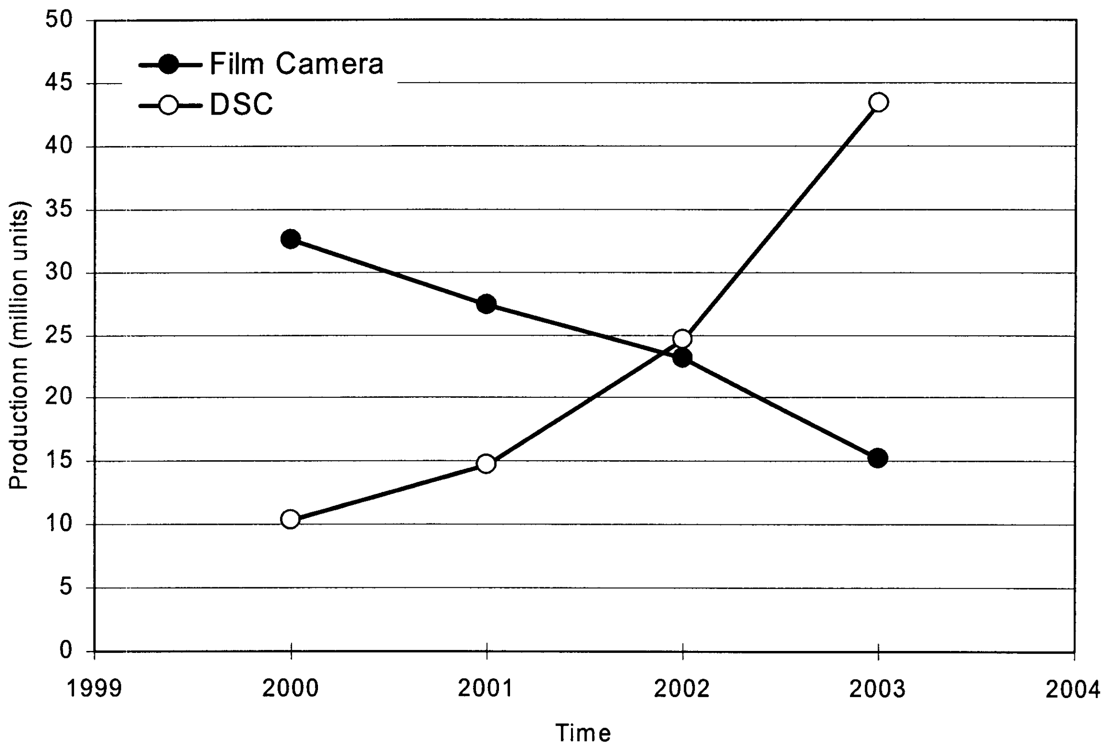

Figure 3-2 Shipments in Japan of DSCs and film cameras

Source: http://www.cipa.jp/english/data/index.html

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[51] Christensen, C. M., *The Innovator's Solution*, Harvard Business School Press, 2003, p. 69.

[52] http://www.cipa.jp/english/data/index.html

It is clear that the increase of the DSC business compensates for the decrease of the film camera business in the incumbent company. The reason the incumbent company could manage its DSC business well is that they utilized alliance, headhunting, and OEM as the preparation against the DSC, as mentioned in Chapter 2. This example shows how important it is for the company to consider the product disruptive technology in order to reduce the damage or in order to take advantage of the opportunity. The product disruption might kill the company if the company fails to prepare it.

3.2. Product disruption change value network

The product disruption sometimes causes a dramatic change in an existing value network. Christensen and Richard S. Rosenbloom showed their concept of value network in their research, and mentioned that companies are embedded in value networks and that components at each level are made and sold to integrators at the next higher level in the system through these value networks.[53] As shown by the example of the disk drive in their research, the product usually belongs to many value networks.[54] These value networks are based on not only similar upper-level products such as mainframe computers, notebook computers, and engineering workstations for disk drives, but also completely different upper-level products. For example AC/DC converter belongs to many value networks in which upper level products are notebook PCs, DVDs, and copiers so on. On

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[53] Christensen, C. M. and Rosenbloom, R. S., "Explaining the attacker's advantage: technological paradigms, organizational dynamics, and the value network, *Research Policy*, 24 (1995) 233-257.

[54] Ibid., p. 239.

the other hand, AC/DC converter belongs to the value network which provides DC power to electric appliances. The value network includes power station, substation, and power line so on.

Here, we treat the fuel cell which is the product disruptive technology against the DC power supplier such as AC/DC converters and batteries. The fuel cell has the potential to change an electricity supply system from a centralized one to a dispersed one (see Figures 3-3 and 3-4).

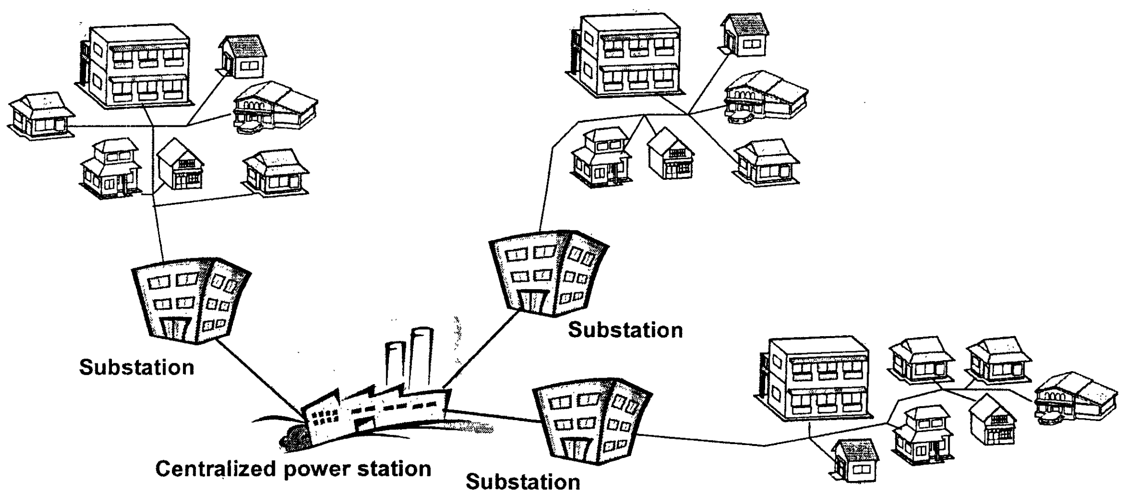

Figure 3-3 Existing centralized electric power system

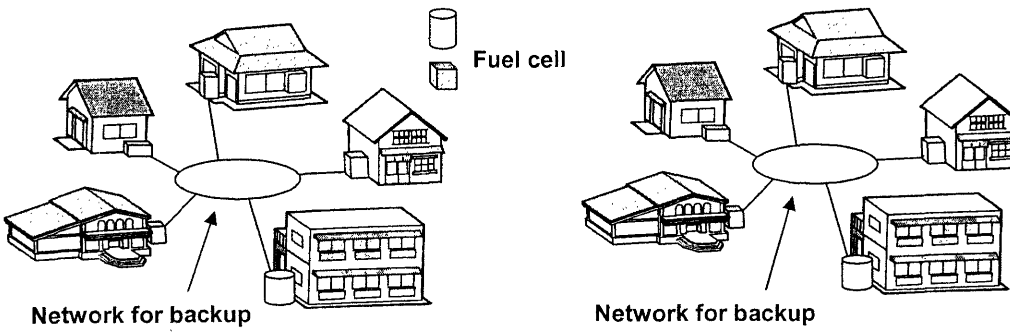

Figure 3-4 Dispersed electric power system

We can see that the centralized power station and substations disappear in Figure 3-4. The fuel cell will disrupt the existing system whose interface is the AC/DC converter if it becomes popular, because each house will be equipped with the fuel cell as a home power generator and not require the electricity from the centralized-type power station. We can easily notice that the fuel cell disrupts the value network itself which includes power station, substation, and power line so on. Jeremy Rifkin mentions the potential of hydrogen energy to disrupt the existing energy system in his book "The hydrogen economy".[55] Companies whose business is related to the existing energy system will be seriously damaged by this change if the fuel cell changes the existing value network itself.

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[55] Rifkin, J., *The Hydrogen Economy: The Creation of the World-Wide Energy Web and the Redistribution of Power on Earth*, Penguin Putnam Inc., 2002, pp. 176-215.

3.3. Summary

Company disruption follows product disruption. In the case of company disruption, the disrupted business occupies the whole or most of the businesses of the disrupted company. The damage caused by the product disruption plunges the company into the disruption. The product disruption sometimes changes the existing value network drastically. This change damages companies related to the existing value network.

4. Complementor for disruptive technology

4.1. What is a complementor?

An external environment affects a company's strategy even though the company has an excellent technology like Microsoft, Intel, and Cisco. Arnoldo C. Hax discussed the complemetor's role clearly in his book "The delta project".[56] According to Hax, a complementor is not a competitor, or necessarily a supplier; it is a provider of products and services that enhance, directly or indirectly, our own offering.[57] The complementor plays a very important role in the process to reach the System Lock-In position, which is the most profitable position among the triangle; The Best Product, Total Customer Solusions, and System Lock-In in the corporate or business strategy. The concept of the complementor is also very important in the disruptive technology especially when we discuss the value-change disruption, which I will explain in chapter 5. When I use the term "complementor" for the disruptive technology, it means all factors to help the technology spread and become the disruptive technology, such as other products, law, and environmental matters so on.

4.2. A complemetor grows the disruptive technology

4.2.1. A case: triacs and mechanical relays

The most straightforward case of the complementor is that the complementor removes the barrier for the emerging technology to become the disruptive technology. A triac could become the disruptive technology against a mechanical relay in the field of AC/DC

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[56] Hax, A. C. and Wilde II, D. L., *The Delta Project*, Palgrave, 2001, pp. 81-104.
[57] Ibid., p. 81.

conversion of motors thanks to micro-controllers. The triac was invented by General Electric Company (GE) in 1963.[58][59] It was the power semiconductor whose structure is shown in Figure 4-1. The on/off state of the triac can be controlled under AC voltage by charging the voltage to the gate. The triac is applied to the electric devices which are powered with the AC voltage, such as a washing machine, a cleaner, AC motor control, heater control and lighting.[60] If we observe the history of the triac, we will notice how the triac disrupted the mechanical relay with help of the micro-controller.

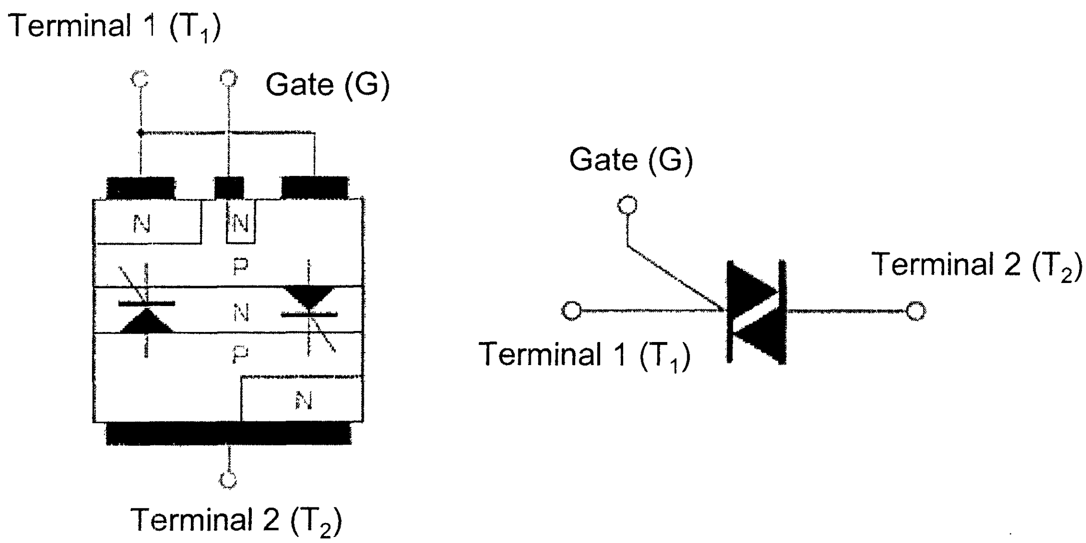

Figure 4-1 Structure of the triac

Source: Toshiba Semiconductor Company, *Semiconductor Guide*, Seibundo Shinkosha Inc., 2001

According to an interview with Kawasaki, a manager of power device department of

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58 http://www.xcvcorp.com/Electronics%20Museum%20HTML.html
59 http://learn.sdstate.edu/shietpas/classes/fall02/ee430/notes/2/d/top2d.pdf
60 Toshiba Semiconductor Company, *Semiconductor Guide*, Seibundo Shinkosha Inc., 2001, p. 39.

Toshiba,[61] people evaluated the potential of the triac when it appeared, because it was useful to control the speed of AC motor. However, a circuit designer could not draw out the ideal performance of the triac for AC/DC motor control because there was no way to control the triac at high frequency in those days. Only a diac, one of the discrete semiconductors, could provide the designer with simple on-off control for a triac. Thus, the triac could penetrate only the area which required simple on-off cycle control, whose cycle is shorter than the shortest cycle that the mechanical relay could control. Thus, designers still continued to use mechanical relays for most of the areas for AC/DC motor control, and the triacs was the product for the niche market such as a heater, a hair drier, and electrically controlled lighting.

In the late 1970s, a micro-controller appeared in some fields such as automotive devices, and Toshiba introduced the first air-conditioner with a micro-controller in 1978.[62] Then, the micro-controller became cheap enough to be applied to home electrical appliances and become popular in 1980s. It provided circuit designers with the solution to control the triac ideally and enabled them to control AC/DC motor electrically, which made possible the complex speed control of the AC/DC motor. Once the barrier to control the triac ideally disappeared, the triac quickly spread and became the disruptive technology against the mechanical relay; the triac replaced the mechanical relay rapidly. We can find that the triac couldn't become the disruptive technology by itself because the triac itself couldn't

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[61] Interviews with Mr. Kawasaki, a manager of power device department of Toshiba Corporation, on January 22 and February 10, 2004

[62] http://www.toshiba-carrier.co.jp/company/history/index_j.htm

solve the problem of control. Thus, it must wait for a complementor which could solve the problem. Once the micro-controller appeared and became cheap enough to be popular, the traic started to disrupt the mechanical relay. This is the typical example that the complementor grew the disruptive technology.

4.2.2. Performance criteria of customers

A customer has a variety of performance criteria to judge a whole product performance. According to Utterback, many performance criteria were incorporated or will be incorporated into fundamental functions and new criteria will be generated in a product history.[63] Sometimes, the function, which was the key factor for purchase decision, lose the effect on customer's performance evaluation, because it became a basic function which should be equipped with the product; every product came equipped with the function, so customers removed the criterion for the function from their decision making process. I show the camera history from the viewpoint of the customer's performance criteria in Figure 4-2.

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63 Discussion with Prof. James M. Utterback on April 12, 2004.

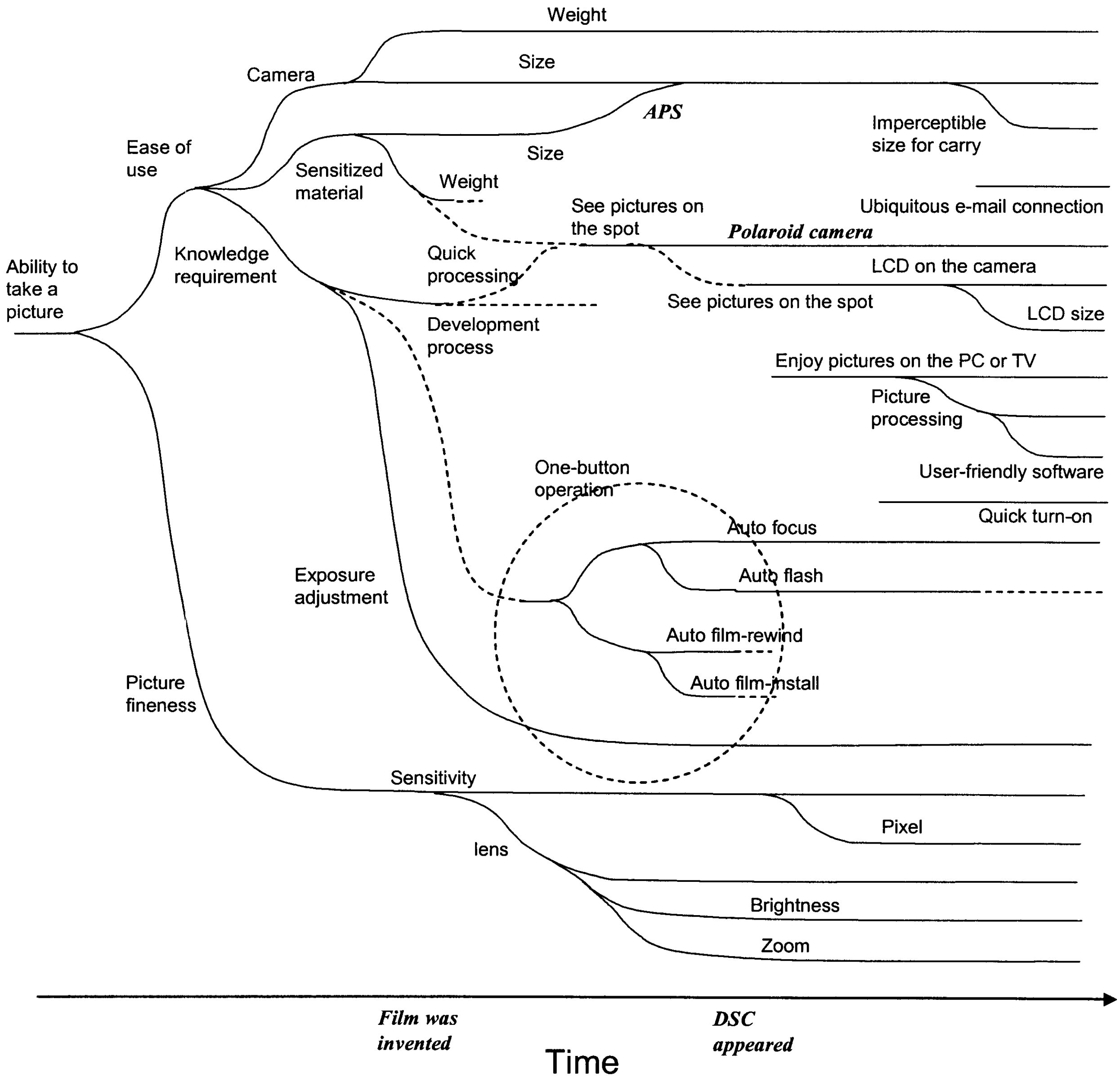

Figure 4-2 Performance criteria of the camera

People started to take pictures thanks to the camera. The primary performance criterion was the Ability to take a picture. The performance criteria of both Ease of use and Picture fineness followed it. As shown in Figure 4-2, the performance criterion, Weight of sensitized material (glass plate), was incorporated into film itself after film was invented, because it was much lighter than glass plates.[64] We can think that Size of the sensitized material (film) merged with that of the camera, because the camera with advanced photo system (APS) was introduced; camera manufacturers judged that they couldn't shrink the camera size due to the film size and started to develop the new camera system with a small film. Customers incorporated the performance criterion, Development process, after Eastman Kodak Company introduced new picture-taking system, which released users from troublesome development process. Interestingly, the incorporated performance criterion, Development process, was reshaped into another performance criterion, See pictures on the spot, provided by invention of Polaroid Camera, and revived especially after DSC became popular. People could enjoy pictures they took on the spot through LCD without development process, and the new way of use created the new performance criteria, LCD on the camera (whether LCD is equipped with the camera) and LCD size. Thanks to progress of electronics, manufactures could design the camera with one-button operation and user learned how convenient the function was. Thus, the new criterion, One-button operation, joined in the performance criteria. However, two functions of One-button operation were incorporated into the DSC – auto film rewind and auto film install (I focus on DSC users here although the film camera still survives). Some people

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[64] Utterback, J. M., *Mastering the Dynamics of Innovation*, Harvard Business School Press, 1996, pp. 172.

felt the start-up time of DSC was slow, so the criterion, Quick turn-on, was generated. Some users, especially users of mobile phone with a camera, knew how convenient it was if they could send a picture by e-mail soon after they took the picture; Ubiquitous e-mail connection joined in the criteria.

Both the generation and incorporation of performance criteria have occurred over and over again with a trigger, such as introductions of new technology and value, or with just a gradual value change through the product history. We can notice that a complementor was sometimes involved in the process. For example, a micro-controller enabled engineers to add the function of the fine temperature control to the air-conditioner. Once users know how convenient the new function is, they usually add this function to the list of criteria. In case of the micro-controller, users added the fine temperature control function to their criteria. If the added criterion is important for users, manufacturers must follow the new criterion to survive in the market in which customers appreciate it.

So far, we discuss the performance criteria along the time axis. Here, we discuss the customer's performance criteria along the vertical axis. If we discuss the criteria of 2003, they consist of Size, Ubiquitous e-mail connection, LCD size, User-friendly software, Pixel, and Brightness so on (see Figure 4-3).

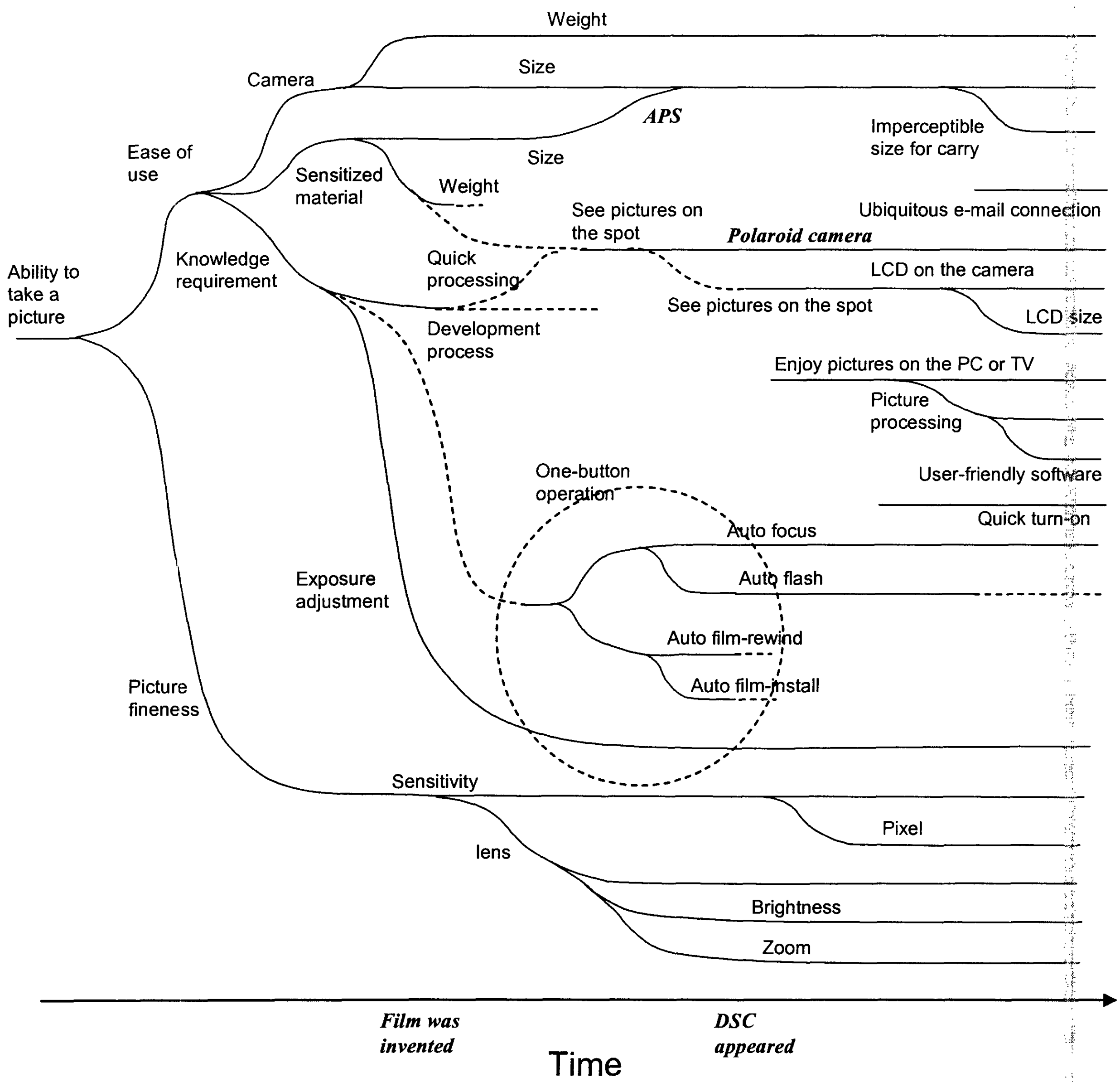

Figure 4-3 Performance criteria of the camera with the vertical axis

The most important criterion to judge the performance of the product depends on the customer. For example, Size and Weight might be important for people who want to carry a camera at every place so that they can enjoy taking a picture anytime. It is very popular among young people in Japan to send pictures by e-mail though a mobile phone. Elder people might want to have a camera with a large LCD screen because of weak eyesight. Professional photographers might make much of both Pixel and Brightness. Of course, it is too much to say that professional photographer does not care the other criteria such as Size and Weight. People choose the product with almost common criteria although his or her priority is very different from the others. If we limit the performance criteria only to along the vertical axis, the total performance can be shown as the following equation. (This equation is very conceptual and the track of the disruptive technology will not be a line if we depict it on the performance vs. time graph. However, the equation is very helpful to understand the performance criteria of customers.)

$$P = \sum_{i=1}^{n} a_i P_i \qquad (5\text{-}1)$$

Here, a_i is a coefficient of performance *i*, which shows the priority of a customer, and P_i is performance *i*, which are willingly considered by customers and are along the vertical axis in performance criteria figure. Coefficients of equation (5-1), which show the importance of criteria, are changed by a complementor through the priority change along the vertical axis. (We can substitute zero for the coefficient when a customer doesn't care the performance because of individual preference; we can also do so because of the incorporation of the performance criterion, but this substitution should be treated only at the moment of the value change.) If something, such as enforcement of a new law, changes coefficients and the change affects the total performance dramatically and positively from the customer point of view, it should be a complementor for the product.

4.2.3. A case: triacs and inverters

Consider the inverter for a home electrical appliance such as an air-conditioner and a washing machine.[65] Inverters were applied to industrial machines first, but they could not gain mass popularity. Some time later, they started to become popular due to the application to a home electrical appliance such as an air-conditioner, thanks to the appearance of both DC brushless motors and bipolar transistor modules for an inverter. DC brushless motors became popular through the improvement of efficiency of the inverter, and then both DC brushless motors and inverters interacted positively and helped each other to be popular.

In 1980, Toshiba launched the first inverter air-conditioner.[66] The AC motor was used in the inverter air-conditioner in those days. The inverter was the revolutionary technology in improvement of efficiency, because, unlike the triac, the inverter could apply the appropriate voltage to the AC motor according to its revolution speed. That is to say, the inverter could apply appropriate voltage to each cooling level, such as warm, cooler, and

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[65] Interviews with Mr. Kawasaki, a manager of power device department of Toshiba Corporation, on January 22 and February 10, 2004

[66] http://www.toshiba-carrier.co.jp/company/history/index_j.htm

coolest. Therefore, the inverter could improve total efficiency of air-conditioner compared to the triac. However, the cost of inverter was more than 20 times of that of triac, because the inverter required many additional components such as a drive circuit and power devices. The inverter in a home electrical appliance became popular in early 1990s only in Japan. This unique popularity resulted from an energy-saving character and noise reduction. For example, the inverter air-conditioner is not popular in the United States because the electricity charge is cheap, and because a wide house solves the problem of noise. In Japan, salespersons show their customers how much the inverter air-conditioner saves the electricity charge in order to sell their expensive air-conditioner. In addition, the government supported to spread the energy-saving products by the law and regulation. Noise reduction was also important factor in the case of washing machines in Japan. Many people, who worked until night and lived in small apartment houses, wanted quiet washing machines so that they could do the laundry at late night. These advantages compensated for the higher price of inverter home electrical appliances. This case clearly shows that high electricity charge and small housing were complementors for the inverter in Japan, because the inverter home electrical appliance hasn't been popular in the United States, where the electricity charge is cheap and houses are big.

Here, we review the product disruption caused by the inverter from the viewpoint of electric components.[67] Many kinds of high voltage transistor for the inverter appeared during the early period of the product disruption. Semiconductor engineers tried to

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[67] Interviews with Mr. Kawasaki, a manager of power device department of Toshiba Corporation, on January 22 and February 10, 2004

develop the new device for the inverter because the bipolar transistor, which was used then for the inverter, was not easy to control. The need led to the invention of new devices. For example, Insulated Gate Bipolar Transistor (IGBT), which is suitable for the inverter, was invented by GE in 1983.[68][69] Thanks to the MOS structure of IGBT, it was improved rapidly with sustaining technologies. DC brushless motors also appeared in this period and made motor control with the inverter easier. These new devices became also complementors for the inverter. Thus, we can say that both complementary environmental factors and complementary new technological factors grew the inverter as the disruptive technology of the triac.

4.3. Find a complementor

When the emerging technology appears, it often happens that the technology is more expensive than the conventional technology, especially because it cannot enjoy economies of scale. A fuel cell is one of the examples. When fuel cell technology started to be positioned as a promising future technology, both the automobile industry and the home power generation industry expected each other to be a complementor for a fuel cell in order to reduce cost dramatically with economies of scale. The cost is often the biggest problem for the emerging technology to be popular, and thus an industry often expects another industry to lead the market so that it can enjoy economies of scale. Besides, many technologies have some critical problems which prevent them from becoming mainstream. Finding complementors is very useful for solving the problem.

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[68] http://www.pels.org/comm/Awards/Newell/baliga.html

[69] http://learn.sdstate.edu/shietpas/classes/fall02/ee430/notes/2/d/top2d.pdf

Here, we treat hydrogen production with photovoltaic electrolysis. There are several emerging hydrogen production technologies, which have not been able to become the disruptive technology against conventional technologies, which use fossil fuels. I will show the possibility of photovoltaic electrolysis in hydrogen production for causing disruptive innovation by focusing on its potential complementor, as follows.

Many people are concerned about a shortage of fossil fuels and global warming. The hydrogen production with photovoltaic electrolysis is a method to produce hydrogen from water with a photocatalyst by using solar energy. Many researchers have been tackled this topic since Dr. Honda and Dr. Fujishima found that hydrogen and oxygen can be produced from water with an electrochemical cell, including a titanium dioxide (TiO_2) electrode, by irradiating solar light in 1972.[70] The mechanism of water dissociation with photocatalyst is shown in Figure 4-4.

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[70] National Institute of Science and Technology Policy, *Suiso Enerugi Saizensen* , Kogyo Chosakai Publishing Co., Ltd., 2003, p. 161.

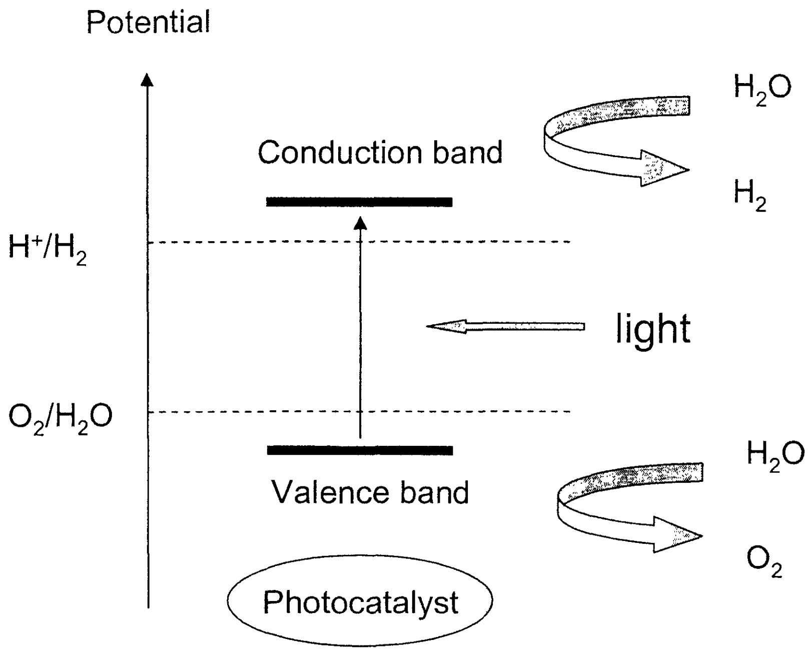


Figure 4-4 Mechanism of water dissociation with photocatalyst

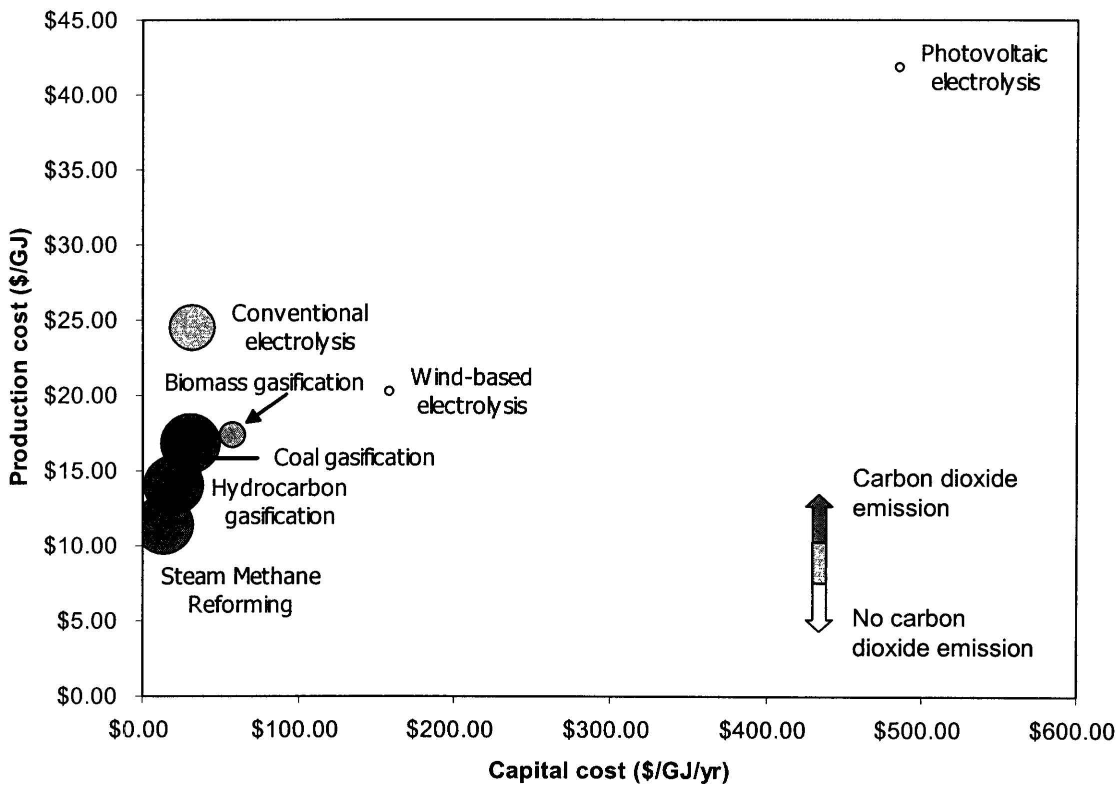
Source: National Institute of Science and Technology Policy, *Suiso Enerugi Saizensen*, Kogyo Chosakai Publishing Co., Ltd., 2003, p. 161.

When the photocatalyst absorbs solar energy, an electron jumps up from the valence band to the conduction band. If the potentials of the electron and an electron hole exceed the level where water can be oxidized and deoxidized respectively, the electron will generate hydrogen by deoxidation and the electron hole will generate oxygen by oxidation.[71]

Here, we analyze people's evaluation of the technology. The advantages of the photovoltaic electrolysis are no emission of carbon dioxide, ease of mass-storage,

[71] Ibid., pp. 161-162.

exhaustless amount of energy, and even distribution so on. These characteristics appeal to some customer's value criteria of the technology such as environmental-friendly and stability in supply. However, the present production cost is quite expensive (see Figure 4-5), and the technology maturity is low; a conversion efficiency is still quite low, and the transportation and storage of hydrogen have some problems. These disadvantages devalue the evaluation of the technology in value criteria of efficiency, cost, and safety.



Note: Circle size is related to production amount.

Figure 4-5 Cost of each technology

Source: Research report of 15.365J at Massachusetts Institute of Technology[72]

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[72] Gibney, J. R., Nevoy, H., Resnick, R., Siljan, OJ., Kameda, M., "Hydrogen production", 15.365J Disruptive technology: predator and prey?, Massachusetts Institute of Technology, 2004

Some complementors are supporters who strengthen the advantage of the technology, and others are sweepers who remove its disadvantage or problem. A government support is a typical supporter (see Table 4-1). It invests money, organizes the human resource, gathers people's attention to the technology.

Project	Country	Technology	Duration
Euro Quebec Hydro－Hydrogen Pilot Project	Canada, EU	Waterpower(100MW)-Electrolysis	1986-1999
Hydrogen from Solar Energy Project (HYSOLAR)	Germany, Saudi Arabia	Solar light(10kW)-Electrolysis(350kW)	1985-1996
Solar Wasserstoff Bayern Project $WB)	Germany	Solar light(350kW)-Electrolysis(200kW)	1989-1999
World Energy Network Project (WE-NET)	Japan	Waterpower(4000MW)	1983-2020
Transpotation System	Iceland	Waterpower, Geo thermal energy	1999-
US Hydrogen projects	US (DOE)	Solar light-Electrolysis, Biomass	1994-
PHOEBUS Project	Germany	Solar light(40kW)-Electrolysis	1991-1999
ARGEMUCH$_2$ airport project	Germany	Electrolysis(450kW), Natural Gas	1996-2000
Solar-Hydrogen System	Canada	Solar light-Electrolysis	1992-

Note: examples are not limited only to photovoltaic electrolysis

Table 4-1 Examples of the governmentally supported project

Source: Osumi, Y., *Suiso Enerugi Riyou-gijutu*, Agne Gijutsu Center , 2002, p. 153.

A scientist warning is also a supporter-type complementor. It emphasizes the positive characteristics of no emission of carbon dioxide and exhaustless amount of energy. Thus, the strategy for appealing to the environmental-friendly factor is to cite the warning in order to affect public opinion. Unstable international situation is also a support-type complementor because the situation will make it difficult to obtain oil constantly; hydrogen energy with photovoltaic electrolysis doesn't have geographical risk like petroleum or hydrogen production from fossil fuels. The complementor emphasizes both even distribution and ease of mass-storage characteristics of the technology. The price increase and new tax on fossil fuel might help the technology in the cost competition, because they increase the costs of the conventional methods, which use fossil fuel. People might notice the size merit of equipment by the deregulation of installation condition. The efficiency and the production cost are closely related; the production cost will be reduced if the efficiency is improved. Many materials, which operate under ultraviolet light, have been found so far, but the ultraviolet light occupies only a small part of solar light. Thus, the development of the new material which works with radiant energy is important to improve the efficiency. This new technology might remove the cost problem. Compact and light materials for hydrogen storage will remove the problem of transportation. More stable storage methods are preferable from the viewpoint of safety. We can analyze the pros and cons of the technology, evaluate both technology and market trends, and examine each possibility to be the effective complementor.

4.4. Summary

A complementor is a useful concept when we discuss disruptive technology. It is defined as all the factors to help the technology spread and become the disruptive technology. The complementor sometimes grows the disruptive technology. We can find that it removes the barrier for the emerging technology and that the technology becomes the disruptive technology.

A customer decides which product they purchase from the many points of view. That is, the customer's evaluation of performance consists of each partial evaluation. The complementor affects the weight of each partial evaluation, is involved in both generation and incorporation of performance criteria, and changes customer's total evaluation and the performance dimension. Therefore, it is very important to utilize the power of complementors when we introduce an emerging technology. The possibility that the technology becomes the disruptive technology will increase dramatically if we can find the appropriate complementors for the technology. Complementors emphasize its advantage or solve the critical issue for the technology.

5. Successive disruption

5.1. Does the disruption stop?

Constantinos D. Charitou and Constantinos C. Markides mentioned that new way of competing grows to control a certain percentage of the market but fails to overtake the traditional way completely, and showed the example that disruptive innovation didn't completely replace the incumbent way.[73] Christensen refuted them as follows. "Disruption is a process and not an event. The forces are operating all of the time in every industry. In some industries it might take decades for the forces to work their way through an industry. In other instances it might take a few years. But the forces – which really are the pursuit of the profit that is associated with competitive advantage – are always at work."[74]

This refutation is right in his definition. However, we can get to a different conclusion if we observe it from the different point of view.

5.2. Multi-technology trajectories

We basically targeted one key performance criterion for each product to make the discussion simple. However, a final product is never composed of only one performance criterion, and each has corresponding technologies. For example, advanced electrical products, such as DVDs and flat panel TVs, are said to involve several hundred patents if

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[73] Charitou, C. D. and Markides, C., "Responses to Disruptive Strategic innovation", *MIT Sloan Management Review,* Vol. 44 Issue 2, Winter 2003, p. 58

[74] Christensen, C. M., *The Innovator's Solution*, Harvard Business School Press, 2003, pp. 69-70.

we consider manufacturing and substitute technologies. Each technology has its own trajectory of the sustaining innovation, and thus the final product includes many trajectories of sustaining technologies even though it is just a simple component. Table 5-1 shows performance criteria, and sustaining technologies of Note PC just as an example.

Final Product	Performance criteria	Sustaining technologies
Note PC	Processing speed	Fine fabrication
		Material
		New circuits and system design
		Lithography and mask
		Heat radiation
	Operation time without an adapter	Battery capacity
		Energy density
		Power supply
		Gate stack
	Size	High frequency operation
		Heat radiation
	Durability	Reliability test
		Measurement
		Material
	Visibility for display	Backlight
		Cell design for LCD
	⸾	⸾

Table 5-1 Performance criteria and sustaining technologies of Note PC

5.3. Value-change disruption

5.3.1. Concept of value-change disruption

Introducing the concept of both the multi-technology trajectories and the complementor into disruption allows us to understand how the emerging technology becomes the disruptive technology. As mentioned in 4.2.2, the complementor changes the weight of each performance criterion and then changes the performance dimension; it sometimes even extinguishes a performance criterion by incorporating it in the product. We also notice that the product can survive if the incorporated or generated performance criterion doesn't cover all products which are under various circumstances, because the disruption operates only within the area where the performance is valued by customers. If the product outside the covered area is disrupted, it is because the corresponding disruptive technology appears which is directly related to the area where the disrupted product is positioned. I show this concept in Figure 5-1 as a framework.

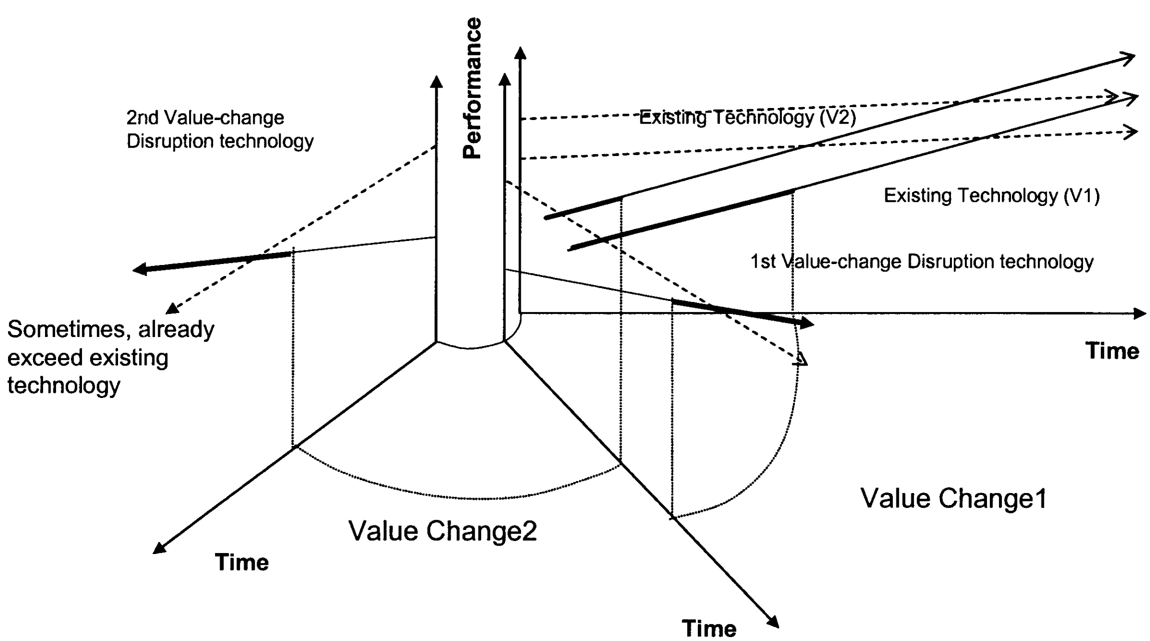

Figure 5-1 Value-change disruption

Because the complementor changes some customer performance criteria, which are directly related to one of the existing technologies (usually an emerging technology which has not been the disruptive technology for some reasons), the evaluation of the technology rises and exceeds the evaluation of the mainstream existing technology and then starts to disrupt the mainstream technology. (The evaluation of the mainstream existing technology also changes by the value change.) The value change creates a different value network, and the network is different from the one created by the new-market disruption.[75] This axis shouldn't be "nonconsumers or nonconsuming occasions". That is, customers purchase the disruptive product not because they can afford to buy it thanks to the much cheaper price than the incumbent product, nor because they can use the disruptive product thanks to its convenience to use unlike the incumbent product, but because their values change enough to evaluate it highly as a worthy product.

Since the disruption operates only within the area where the value change can cover, the value-change disruptive technology can't disrupt the product outside the area. For example, a triac, for AC/DC motor especially in a washing machine and an air-conditioner, was a disruptive technology against a mechanical relay within the value criteria of power consumption, and could not disrupt products outside that value criterion. After a triac became the disruptive product with help of a micro-controller, many mechanical relays in a washing machine were disrupted by triacs. However, a washing machine with a mechanical relay still survives in countries with cheap electricity charges like United States. This is not because a mechanical relay ran away toward the high-end market of AC/DC motor in a washing machine and an air-conditioner, but because the surviving machine is

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[75] Christensen, C. M., *The Innovator's Solution*, Harvard Business School Press, 2003, pp. 43-49.

outside the value criterion of power consumption. That is, power consumption isn't the request from customers who use such kinds of machine. The triac can disrupt the mechanical relay within the criteria, but another disruptive technology for other performance is necessary in order that the triac disrupts the product outside the criteria.

An inverter provides us a good example of successive value-change disruptions. In the early 1990s the inverter air-conditioner became popular, because people gradually understood that inverter was necessary for the energy saving and reduced their electricity charge thanks to the campaign of the government and manufacturers.[76] Then, the inverter was added to the list of performance criteria. The performance dimension change, which was caused by the complementor, involved manufacturers in competition to develop excellent inverter air-conditioners in order to survive in the market where customers appreciate the performance of the inverter. The laws also contributed to the spread of inverter air-conditioners. Top runner program were the strongest supporter-type complementor among these laws. It is one way of setting target standard values for energy consumption efficiency of equipment, and is based on the concept that manufacturers produce products which are better than products with the highest energy consumption efficiency of all the products which are currently sold on the market.[77] This obligation made manufacturers concentrate on developing highly efficient air-conditioners, and the inverter was only the option for manufacturers to achieve this requirement. The

[76] Interviews with Mr. Kawasaki, a manager of power device department of Toshiba Corporation, on January 22 and February 10, 2004

[77] http://www.eccj.or.jp/top_runner/index.html

inverter sold well regardless of the expensive price, because both high electricity charge and the law, the complementors for the inverter, changed both the weight of the criteria and the performance dimension.

However, the energy-saving characteristic could not be a strong advantage in a washing machine unlike in the air-conditioner; because the power consumption of the washing machine is not so big though that of the air-conditioner occupied about the quarter of whole power consumption at home.[78] However, people gradually appreciated the quiet operation of the inverter with the increase of the households of living-alone and working-together, because they wanted to do the laundry late at night. Some manufacturers noticed this demand and concentrated on developing the washing machine whose operation was very quiet. Thanks to the new technology of direct drive inverter motor (the motor drives a wash tank directly without a belt), they could successfully develop the quiet washing machine and launched it into the market. Regardless of high price, it sold well; because the change of household structure created a new performance criterion, Quiet. The second value change has disrupted the inverter product (the washing machine) positioned outside the area the first value change covered (the inverter air-conditioner). If the new performance criterion, Quiet, becomes more important, the manufacturers who can't follow it will have a serious problem in the washing machine business.

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[78] http://www.eccj.or.jp/housereform/re15.html

The other value-change disruption is the case that customer's evaluations of two technologies are reversed. Figure 5-2 shows the disruption as a framework.

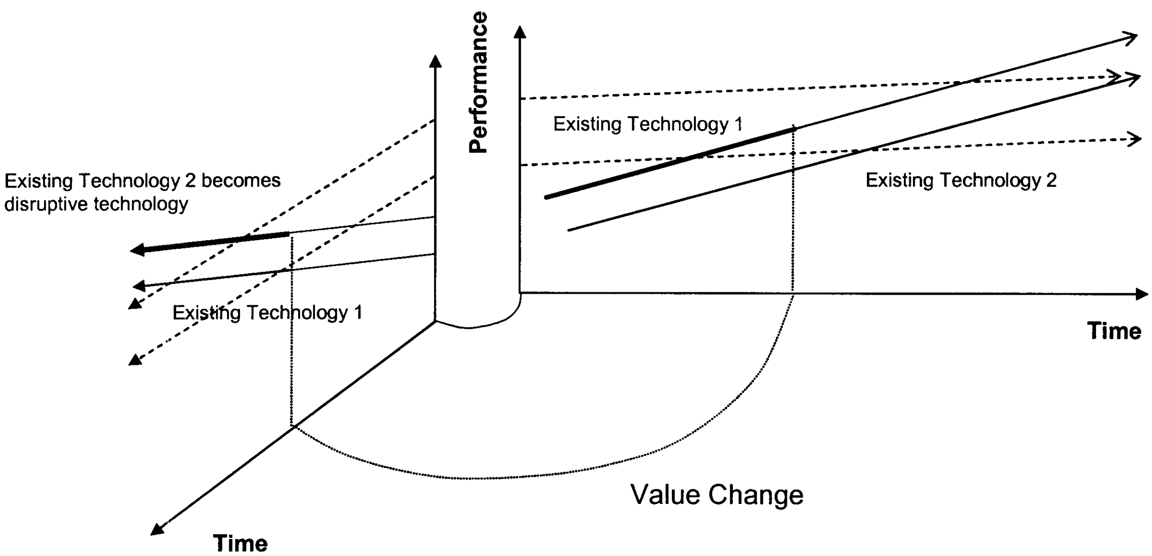

Figure 5-2 Value-change disruption

I mention the programmable logic device (PLD) as an example.[79] Figures 5-3 and 5-4 show the classification of logic IC and the characteristics of semi-custom logic IC respectively.[80]

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[79] Interviews with Mr. Daiko, a manager of small signal device department of Toshiba Corporation, on January 22 and April 16, 2004

[80] Daiko, H., *Tranjisuta-gijutu Special No. 58*, CQ Publishing, 1997, pp. 53-55.

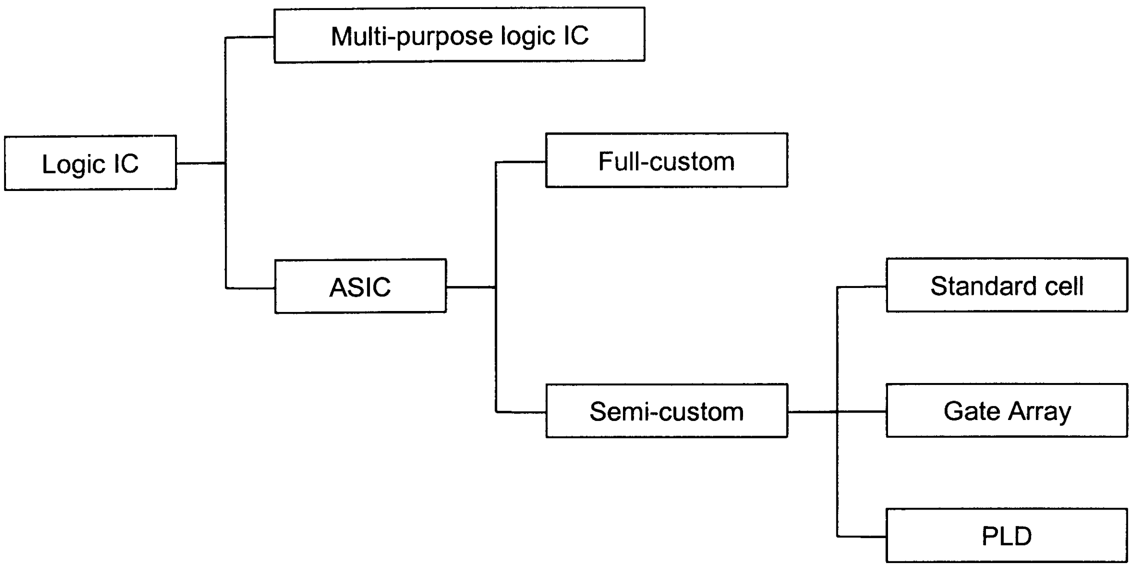

Figure 5-3 Classification of logic IC

Source: Daiko, H., *Tranjisuta-gijutu Special No. 58*, CQ Publishing, 1997, p. 53.

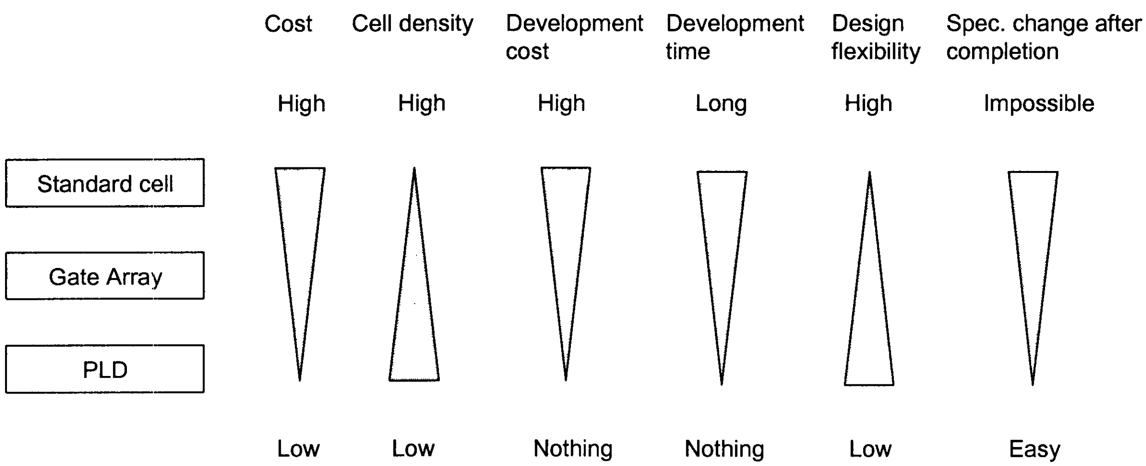

Figure 5-3 Characteristics of semi-custom logic IC

Source: Daiko, H., *Tranjisuta-gijutu Special No. 58*, CQ Publishing, 1997, p. 55.

A Standard cell was suitable for large systems because of its high cell density, and a PLD was suitable for small systems and could be developed with low cost. A gate array was positioned in the middle between them and could be applied to both systems. Engineers evaluated the gate array more than the PLD at first because PLD had low cell density and quality problems. Semiconductor manufactures also considered PLD and gate array as an appropriate technology for prototyping and experimentation and mass-production, respectively; thus, they underestimated the potential for the PLD market. However, the engineers noticed how convenient the PLD was, because they could change the specification very easily, even after it was manufactured. In addition, semiconductor manufacturers came to develop higher performance PLDs, including Field Programmable Gate Array (FPGA) and Complex Programmable Logic Device (CPLD), with low price (cost) and short development times. All this meant that engineers could start product development without fixing the final specification and that they don't have to take the risk of specification changes in product development. They could also use the PLD in testing LSI functions and apply it to the first mass-production model to reduce the risk of large investments, regardless of dull sales; in short, they could decide to manufacture or not manufacture the LSI after confirming the popularity of the product. These advantages of PLDs were spotlighted through severe competition, which requires engineers to shorten the development time and reduce the risk in product development. The requirements therefore created the new criterion, Easy de-bug, and put more importance on Short development time, reversing the customer's evaluations of two products. Many engineers started to adopt more PLDs than gate arrays according to the perception change. In the end, the market for PLDs became much bigger than that for gate arrays.

We can also see how the gate array has been disrupted from a different point of view.[81] Many gate array users adopted System on Chip (SoC) LSIs which are a high-end disruptive technology for the gate array. The gate array was attacked from both the low-end and high-end markets (see Figure 5-4). Therefore, middle ground products, which cover a wider area but often without a specific strength, are sometimes attacked from both markets and plunged into serious situations.

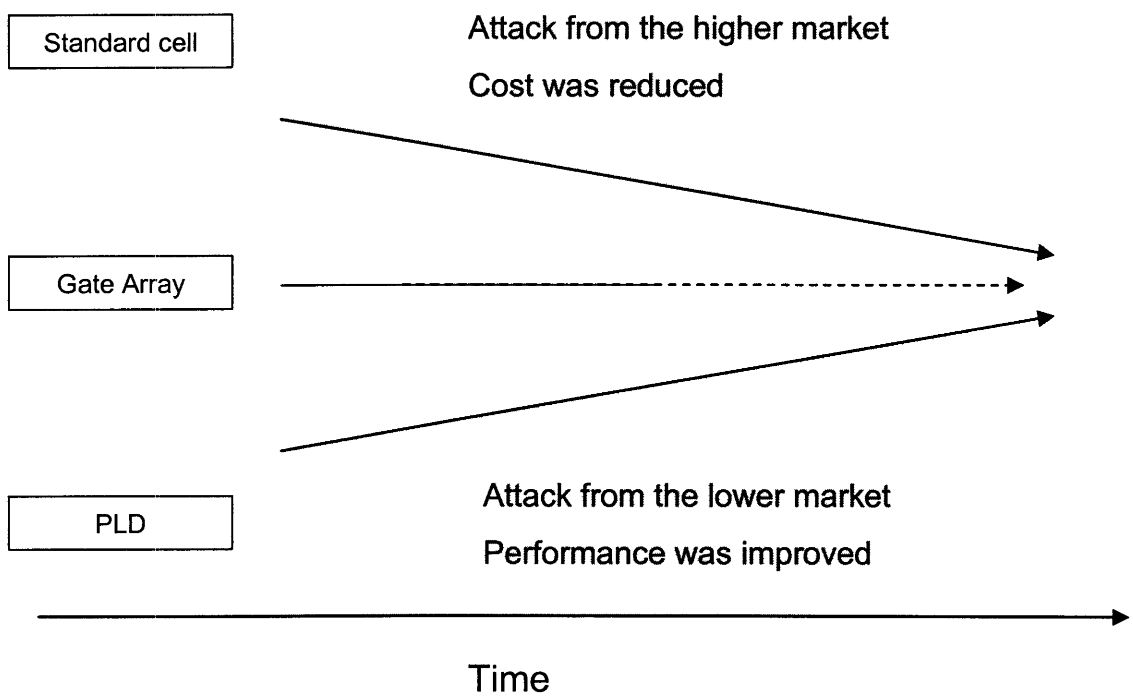

Figure 5-4 Attacks from both low-end and high-end markets

Source: Discussion with Prof. James M. Utterback on April 16, 2004.

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[81] Discussion with Prof. James M. Utterback on April 16, 2004.

5.3.2. Value-change disruption in the assembled product

Disruption is a relative term, as Christensen mentioned[82], and many emerging technologies have the possibility to be the disruptive technology if there is strong help by a complementor. We already discussed a non-assembled product, triacs and mechanical relays; so I will expand this concept to an assembled product.

Here, we discuss the attempt of the aluminum industry to compete in the automobile industry. According to the Hax, the aluminum industry had been particularly aggressive and successful in competition with the copper industry.[83] Aluminum manufacturers were successful in substituting aluminum for copper in automobile radiators, despite the fact that copper delivers superior conductivity. The aluminum industry has been remarkably effective in studying the use of its product. The president of Alcoa Inc. visited the head of General Motors to ascertain their needs and use of aluminum. Alcoa jointly designed with automobile manufacturers new products and technologies to benefit the automobile industry through the use of aluminum. According to Germaine Gibara, formerly president of Alcan Automotive Structures, Alcan Automotive Structures worked with several major automobile manufacturers on the projects and could make automobile manufacturers notice the new use of aluminum in the automobile through demonstration projects.[84] Alcan was involved with a prototype of the Ferrari 408 and worked closely

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[82] Christensen, C. M., *The Innovator's Solution*, Harvard Business School Press, 2003, p. 193.

[83] Hax, A. C. and Wilde II, D. L., *The Delta Project*, Palgrave, 2001, p. 59.

[84] Discussion with Ms. Germaine Gibara, formerly president of Alcan Automotive Structures, at the class of 15.365J at Massachusetts Institute of Technology on February 26, 2004.

with Jaguar on its XJ220 development which adopted an aluminum structure, including a honeycomb structure for the floor area, and aluminium engine, skin, and wheels. After that, Alcan jointly developed NSX, the first all-aluminum car, with Honda Motor Co., Ltd. Honda had flexible structures and was familiar with aluminum from its motorcycle beginnings and for its formula one involvement. She reckoned that it had successfully overcome most of the disadvantages of aluminum in developing the NSX.[85] Alcan's innovation in both the production process and the materials enhanced automobile manufacturers to use aluminum. However, aluminum hasn't become the disruptive technology against copper and steel so far because of its cost.

Copper and steel have advantages of conductivity and strength respectively, which are based on their nature. Thus, it is almost impossible for the aluminum producer to develop the aluminum whose performances in conductivity and strength are higher than copper and steel respectively. On the other hand, aluminum also has an advantage of light weight, which is based on its nature. Alcoa succeeded to substitute aluminum for copper in automobile radiator even though copper's conductivity and cost are superior to those of aluminum, because GM preferred aluminum's superiority of light weight to copper's superiorities of conductivity and cost.[86] Disruptions sometimes proceed part by part in the case of assembled products. Required characteristics for the material depend on the part; that is, the incumbent material competes with the disruptive material in each part

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85 Freeman, M., "Making light of car efficiency - manufacturers look towards aluminum to reduce weight", *The Engineer*, January 17, 1991.

86 Hax, A. C. and Wilde II, D. L., *The Delta Project*, Palgrave, 2001, p. 59.

within the limitation of value criteria based on circumstance. Thus, we will find that aluminum is a disruptive technology for copper or steel in the limited area if we observe disruptions part by part. Another value change is required for a disruptive technology to disrupt the incumbent technology outside the value criteria. In addition, each part has different value criteria. Thus, one disruptive technology doesn't always disrupt the incumbent technology in all parts. In this case, the value-change disruptions might occur successively.

5.4. Limitation from circumstances

Value-change product disruption operates uniformly within the value criteria related to value change under uniform circumstances. In the case of the triac in 5.3, the uniform circumstance is the same way to use a triac, that is, use in a motor control. Customers hire the product or service to have their job done.[87] With the example of a quick service restaurant chain, Christensen explained that the critical unit of analysis is the circumstance and not the customer. As he mentioned in the case analysis, a customer may request a different type of product according to the situation.[88] We can also see this many-sidedness in one component through a variety of applications. The component has possibility of use for a different purpose in a different situation.

For example, a mechanical relay was applied to many applications such as power control

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87 Christensen, C. M., *The Innovator's Solution*, Harvard Business School Press, 2003, p. 75.

88 Christensen, C. M., *The Innovator's Solution*, Harvard Business School Press, 2003, pp. 75-78.

for AC/DC motors or the simple on/off switch of an electronic appliance. A triac could not disrupt all mechanical relays even though it came with the electric control. Since ON-resistance of a mechanical relay is almost zero, it is clear that a mechanical relay is more suitable than a triac for a use under extremely large duty rate and long cycle conditions -- Duty rate is the rate of on-time in a cycle. For example, a mechanical relay is under the condition that duty rate is 0.99 and that cycle is 1000 seconds (on-state in 990 seconds and off-state in 10 seconds). Even though the ON resistance of a triac is improved by the sustaining technology, it will never catch up that of a mechanical relay because of the nature of material. Without another disruption, the mechanical relay in a simple on/off switch will not be disrupted. The electrically insulated structure of the mechanical relay can be an advantage against the triac, especially in automobiles. The mechanical relay will survive without another disruption in this case too.

5.5. Value is one of the keys for disruption

When we feel the threat from a disruptive technology, it is very useful to confirm whether the disruptive technology is a value-change product disruptive technology or not. If it is a value-change one, we should check whether our product threatened by the technology is within the value criteria and under the common circumstance. In order to take advantage of the value-change disruptive technology, we can pay attention to what the customer values, decompose their performance criteria into each factor, and consider a potential value change in each factor. This process is also useful to find the complementor for the disruptive technology.

Value is one of the keys for disruption. Even though it is the company disruption, customers move to the disruptive product according to their value criteria. Only value analysis is not enough in case of the company disruption, but this value analysis process helps us to reduce the risk of the value-change product disruption and prevent our businesses from being badly damaged by the value-change disruption.

5.6. Summary

Many technologies are applied to a final product, especially advanced electrical products. Each technology has its own trajectory of sustaining innovation; the product includes many trajectories of sustaining technologies. We will notice that the disruption operates only within the area where the function is valued by customers if we consider these technology trajectories. A disruptive technology can't disrupt the incumbent technology outside the area.

The value change, which is caused by a complementor, creates a different value network. At the new network, customers purchase the disruptive product, because their values change enough to evaluate it highly as a worthy product. The disruption operates only within the area where the value change can cover. If the compelementor affects customer's value criteria strongly and reverses the evaluations between two technologies, the technology evaluated highly after the value change will start to disrupt the one evaluated highly before. In case of an assembled product, the disruption proceeds part by part and the value-change disruptions might occur successively. The value-change disruption operates uniformly within the value criteria related to the value change under the uniform circumstance. The circumstance is also one factor to limit the disruption.

Customer value is one of the keys for disruption. It is very useful for us to check whether the disruption is or will be caused by the value-change disruptive technology when we face the threat of disruption. If it is caused by the value-change one, we need to judge whether it will affects our product from the viewpoints of the value criteria and the circumstance. Decomposing the customer's value and considering each potential of the value change are quite helpful in order to take advantage of the value-change disruptive technology or in order to find the complementor for the disruptive technology.

6. Conclusion

Even the greatest companies sometimes have serious problem in technological innovation. Disruptive technology is one of the most useful and famous frameworks to handle the serious situation. It analyzes why great companies fail from the viewpoints of the market and technological innovation. The concepts of low-end disruption and new-market disruption are well organized and work so well especially form the company-centric point of view, but we notice that the concepts include many restrictions if we discuss them deeply. However, we can make the discussion much richer if we expand the theory from the viewpoints of customer evaluation, complementary change, and value change. Introducing these concepts allows us to find several types of product disruption (See Figure 6-1).

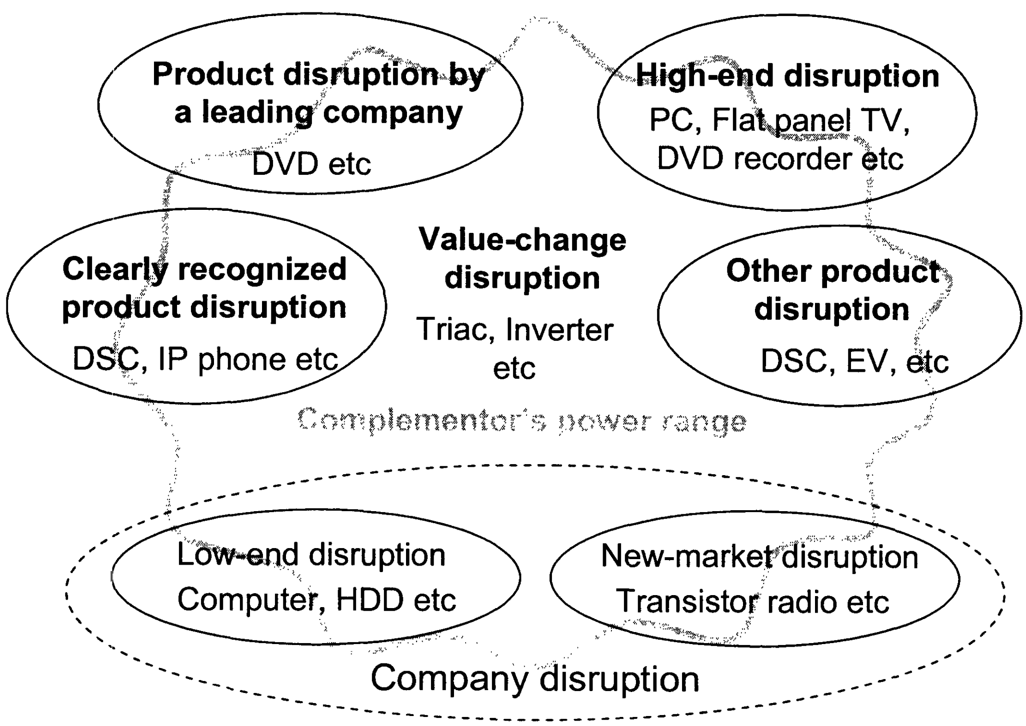

Figure 6-1 Product disruptions

High-end disruption is the mirror case of low-end disruption. The high-end disruptive technology comes with higher performance and cost, and disrupts the incumbent one from the upper market where customers evaluate performance more than cost. While it enjoys the success at the upper market, the high-end disruptive technology is improved in cost; then it moves to the lower market once its cost becomes cheap enough to compete with the incumbent one. A company disruption will follow the product disruption unless the company can tolerate the damage caused by the disruption; the company disruption is a special case of the product disruption. Incumbent companies can prepare against the disruptive technology with technology alliance, OEM, headhunting and so on in order to reduce the damage if they recognized the disruptive technology. A leading company will invest and develop the disruptive technology if it understands the possibility of both market expansion and disappearance of its mainstream product.

Complemetors can change the customer's evaluation by affecting the priority of each value criterion. A supporter-type complementor strengthens the advantage of an emerging technology; on the other hand, a sweeper-type complementor removes problems for the technology to become popular. Complemetors grow the disruptive technology with the value change. Thus, it is very important for the company to understand how complementors work in the disruption and to expect what can be complementors for its emerging technology. If the company can successfully find the appropriate complementor, the possibility that its emerging technology becomes the disruptive technology will dramatically increase. Complementors sometimes incorporate a performance criterion into fundamental functions, or generate a new criterion in a product history (see Figure 6-2), and then change customer's value criteria.

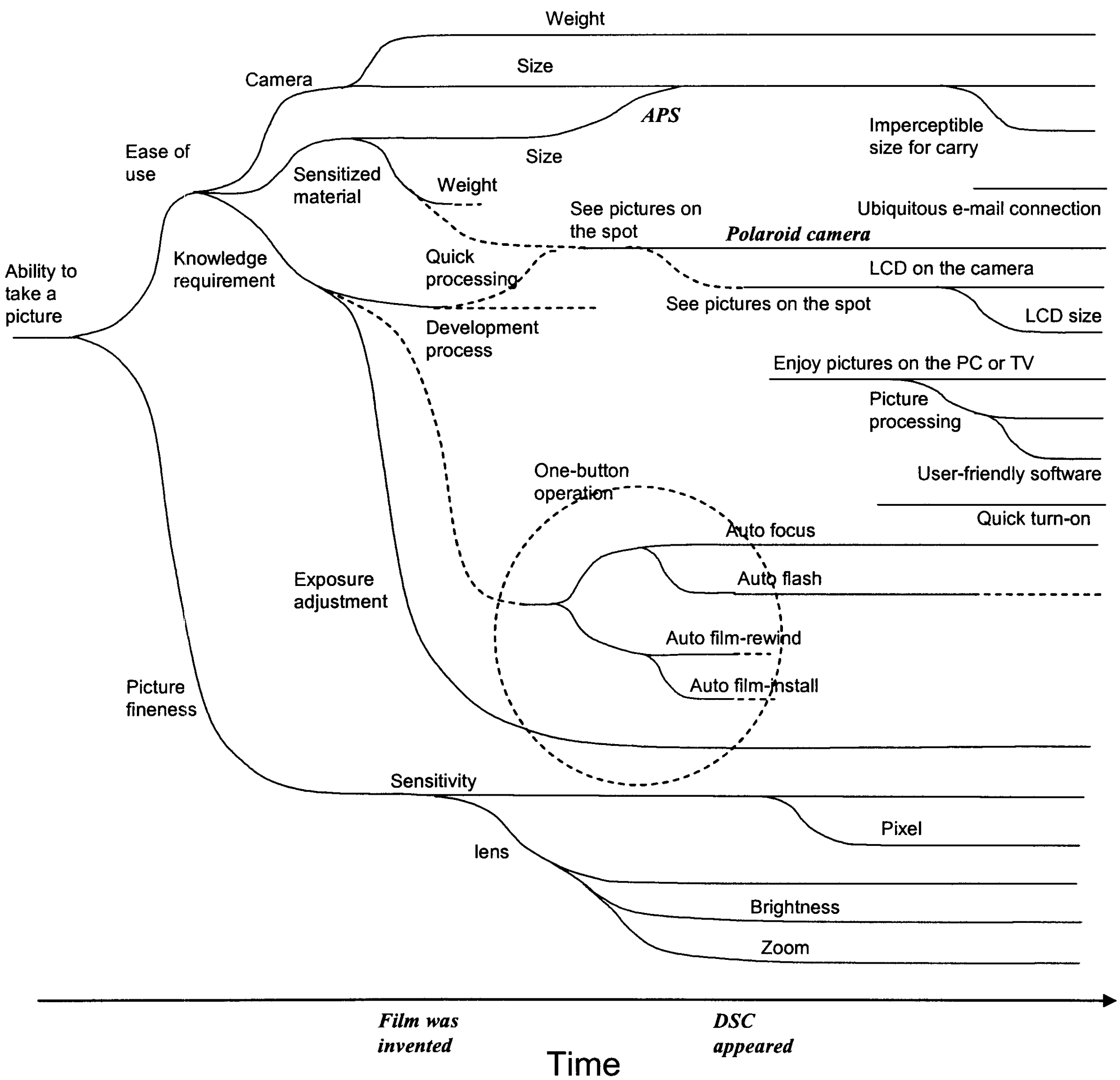

Figure 6-2 Performance criteria of the camera

The value change plunges the incumbent product to the disruption (See Figure 6-3).

1. A complementor changes some customer performance criteria which are directly related to one of the existing technologies.
2. The evaluation of the technology exceeds that of the mainstream technology under the new criteria.
3. The technology starts to disrupt the mainstream technology.
4. Another value change follows it.

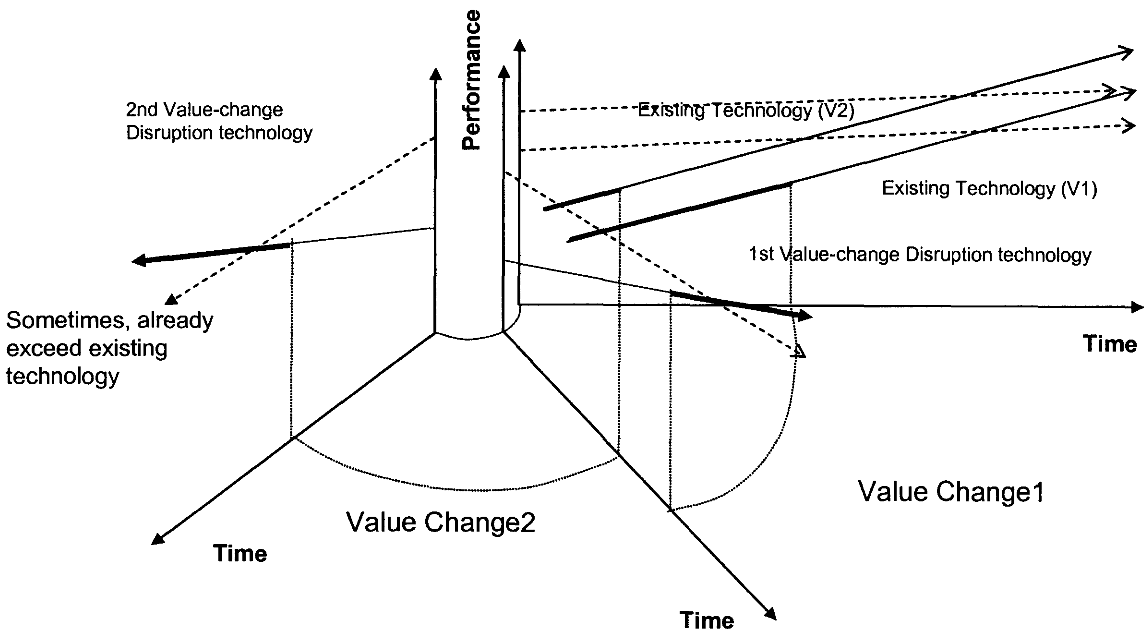

Figure 6-3 Value-change disruption

Since customers purchase the disruptive product according to the high evaluation enhanced by the value change, the value-change disruption can operate only within the area affected by the change. If the product is disrupted outside the area, it will not be because the value-change disruption operates outside the area, but because a corresponding value-change disruption occurs there. Therefore, value-change disruptions might happen successively. If the compelementor reverses the evaluations between two technologies, the technology evaluated highly after the value change will start to disrupt the one evaluated highly before (See Figure 6-4).

1. A complementor changes some customer performance criteria. 2. The evaluations between two technologies are reversed by the value change under the new criteria. 3. The technology evaluated highly after the change starts to disrupt the one evaluated highly before.

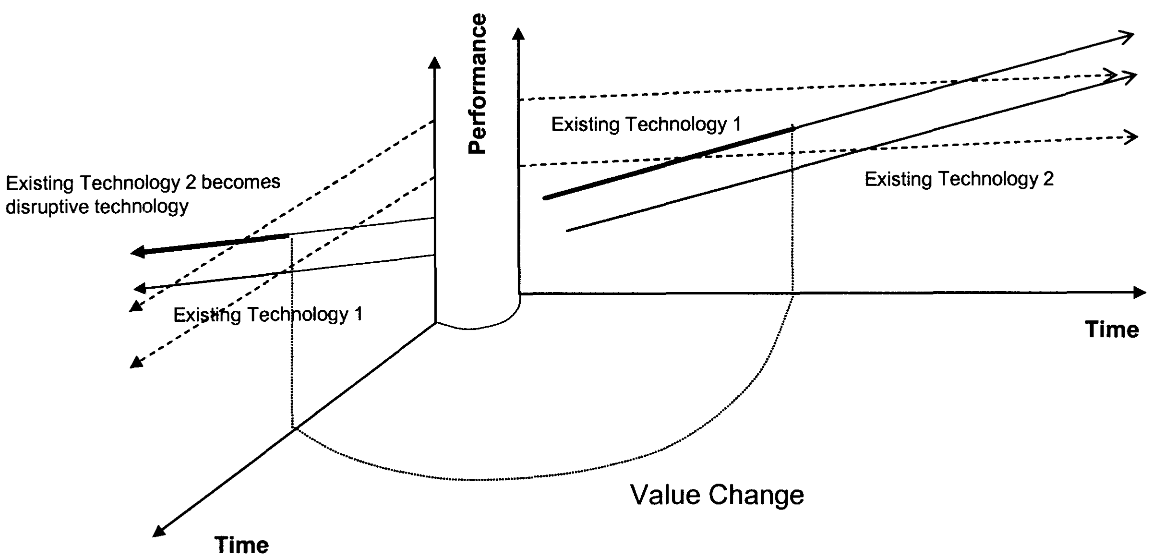

Figure 6-4 Value-change disruption

A product disruption sometimes badly damages a company or plunges it into bankruptcy. On the other hand, some companies enjoy incredible growth thanks to a product disruptive technology. When a company faces a threat or an opportunity provided by disruptive technology, it is very important for the company to examine whether the technology is a value-change disruptive technology or not. If so, it needs to analyze both the area where the value change covers and the one at which situation it is in order to understand how the disruptive technology will function and affect its business. A company can determine the customer's value and then estimate the possibility that the value change happens in each factor in order to expect the value-change disruption. This process also works well to find complementors for its emerging technology. The appropriate analysis will enable the company to assess both the disruptive technology and appropriate complementors, and lead it to the great success.

7. References

Academic articles

Acee, H. J., "Disruptive Technologies: An Expanded View", SM Thesis, Management of Technology, Massachusetts Institute of Technology, 2001

Abetti, P. A., "The birth and growth of the Japanese language word processor: internal venturing in Toshiba Corporation", *Int. J. Technology Management*, Vol. 18 Nos. 1/2, 1999, pp. 114-132

Charitou, C. D. and Markides, C., "Responses to Disruptive Strategic innovation", *MIT Sloan Management Review,* Vol. 44 Issue 2, Winter 2003, pp. 55-63

Christensen, C. M. and Rosenbloom, R. S., "Explaining the attacker's advantage: technological paradigms, organizational dynamics, and the value network, *Research Policy*, 24, 1995, pp. 233-257

Gibney, J. R., Nevoy, H., Resnick, R., Siljan, OJ., Kameda, M., "Hydrogen production", 15.365J Disruptive technology: predator and prey?, Massachusetts Institute of Technology, 2004

Gilbert, C., "The Disruption Opportunity", *MIT Sloan Management Review*, Vol. 44 Issue 4, Summer 2003

Kawashima, M., "Telecom Value Chain Dynamics and Carriers' Strategies in Converged Networks", SM Thesis, Management of Technology, Massachusetts Institute of Technology, 2002

Books

Christensen, C. M., *The Innovator's Dilemma*, Harper Business Essentials, 2003

Christensen, C. M., *The Innovator's Solution*, Harvard Business School Press, 2003

Daiko, H., *Tranjisuta-gijutu Special No. 58*, CQ Publishing, 1997

Fine, C. H., *Clock Speed*, Perseus Books, 1998

Hax, A. C. and Wilde II, D. L., *The Delta Project*, Palgrave, 2001

National Institute of Science and Technology Policy, *Suiso Enerugi Saizensen* , Kogyo Chosakai Publishing Co., Ltd., 2003

Nikkei Micro Device, *Flat panel display 2004*, Nikkei Business Publications, Inc., 2004

Osumi, Y., *Suiso Enerugi Riyou-gijutu*, Agne Gijutsu Center , 2002
Rifkin, J., *The Hydrogen Economy: The Creation of the World-Wide Energy Web and the Redistribution of Power on Earth*, Penguin Putnam Inc., 2002, pp. 176-215.

Toshiba Semiconductor Company, *Semiconductor Guide*, Seibundo Shinkosha Inc., 2001

Utterback, J. M., *Mastering the Dynamics of Innovation*, Harvard Business School Press, 1996.

Business press

"Sanyo Dejikame 7wari Zoukyou", *Nihon Keizai Shimbun*, December 13, 2003

Freeman, M., "Making light of car efficiency - manufacturers look towards aluminum to reduce weight", *The Engineer*, January 17, 1991.

Interviews and discussions

Discussion with Ms. Germaine Gibara, formerly president of Alcan Automotive Structures, at the class of 15.365J at Massachusetts Institute of Technology on February 26, 2004.

Discussion with Prof. James M. Utterback on April 12, 2004.

Discussion with Prof. James M. Utterback on April 16, 2004.

Interviews with Mr. Daiko, a manager of small signal device department of Toshiba Corporation, on January 22 and April 16, 2004

Interviews with Mr. Kawasaki, a manager of power device department of Toshiba Corporation, on January 22 and February 10, 2004

Interview with a manager of the incumbent camera manufacturer on March 17, 2004

Interview with Dr. Mori on March 29, 2004.

Reports

Development Bank of Japan, "Gendai Nihon Sangyo Ron Dai 5kai", October 28, 2003

Okasan Securities Co., Ltd., "Tokusyu Dejitaru Kaden", February 3, 2004

Sanyo Electric Co., Ltd., "Annual report 2003 (Japanese version)", June, 2003

Business press (Internet, April 27, 2004)

Canon Web Site, "Canon Camera Museum, Digital Cameras",
http://www.canon.com/camera-museum/camera/sv/index.html

Canon Web Site, "Development of Still Video (SV) Camera",
http://www.canon.com/camera-museum/history/canon_story/1976_1986/1976_1986_story.html

DigiCamHistory.Com Web Site, "1980-83",
http://www.digicamhistory.com/1980_1983.html

Energy Conservation Center, Japan (ECCJ) Web Site, "Syouene Mimiyori Koramu",
http://www.eccj.or.jp/housereform/re15.html

ECCJ Web Site, "What is the Top Runner Program",
http://www.eccj.or.jp/top_runner/index.html

Fujifilm Web Site, "FinePix Hatsu Sekai Hatsu",
http://www.fujifilm.co.jp/corporate/adgallery/pdf/fujifilm_ad_001.pdf

IBM Press Release on September 27, 2003,
http://www-6.ibm.com/jp/domino05/ewm/NewsDB.nsf/1993/09274

Institute of Electrical and Electronics Engineers (IEEE) Web Site, "Dr. B. Jayant Baliga",
http://www.pels.org/comm/Awards/Newell/baliga.html

IIJ Press Release on September 16, 2003,
http://www.iij.ad.jp/en/pressrelease/2003/0916.html

Japan Automobile Research Institute (JARI) Web Site, "Denki Jidousyatou Dounyuhi Hojo No Goannai",
http://www.jari.or.jp/ja/h16_hojo/index3.html

JCII Camera Museum Web Site, "Dejitaru Kamera Genzai Ni Itaru Kiseki",
http://www.jcii-cameramuseum.jp/events/20001024.htm

NEC Web Site, "Pasokon Hakubutsukan",
http://121ware.com/community/navigate/communication/pcmuseum/index

NTT News Release on September 16, 2003,
http://www.ntt.co.jp/news/news03e/0309/030916.html

Panasonic Web Site, "DVD No Jidai Ga Yattekita",
http://panasonic.jp/p3/dvdram/technology/dvd_world/pages/dvd_world_01.html

PC Watch Web Site, "Pentax Kougaku 3bai Zu-mu No Meishi Saizu Dejikame",
http://pc.watch.impress.co.jp/docs/2003/0204/pentax.htm

Pioneer Press Release on November 25, 1999,
http://www.pioneer.co.jp/press/release63.html

Sankei Shimbun Web Site, "Wa-puro Dounaru? Toshiba Tettai Tasya Tuizuimo",
http://www.sankei.co.jp/databox/pc/0006html/22kei009.htm

South Dakota State University Web Site, "Power Semiconductor Switches",
http://learn.sdstate.edu/shietpas/classes/fall02/ee430/notes/2/d/top2d.pdf

Toshiba Press Release on February 27, 1995,
http://www.toshiba.co.jp/about/press/1995_02/pr2702.htm

Toshiba Press Release on December 8, 1995,
http://www.toshiba.co.jp/about/press/1995_12/pr_j0801.htm

Toshiba Press Release on September 26, 1996,
http://www.toshiba.co.jp/about/press/1996_09/pr2603.htm

Toshiba Press Release on November 16, 2000,
http://www.toshiba.co.jp/about/press/2000_11/pr1601.htm

Toshiba Web Site, "Konohito Ni Aitai",
http://www.toshiba.co.jp/kakan/community/interview/iv05/

Toshiba Web Site, "Rupo Shiri-zu No Rekishi",
http://www.toshiba.co.jp/rupo/history/index_j.htm

Toshiba Web Site, "Toshiba 1gouki Monogatari",
http://www.toshiba.co.jp/kakan/history/1goki/1978wordpro.html

Toshiba Carrier Web Site, "Toshiba Carrier Seihin No Rekishi",
http://www.toshiba-carrier.co.jp/company/history/index_j.htm

XCV Corp., Inc. Web Site, "Electronics Museum",
http://www.xcvcorp.com/Electronics%20Museum%20HTML.html

Statistics (Internet, April 27, 2004)

Statistics, Camera & Imaging Products Association (CIPA),
http://www.cipa.jp/english/data/index.html

Statistics, Japan Electronics and Information Technology Industries Association (JEITA),
http://www.jeita.or.jp/english/stat/index.htm

Statistics Bureau, Ministry of Public Management, Home Affairs, Posts and Telecommunications,
http://www.stat.go.jp/english/index.htm