An Exploratory Study on Understanding the Technological Dimension in Disruptive Innovation

HANG Chang Chieh
Center for Management of Science and Technology,
National University of Singapore,
Singapore.
enghcc@nus.edu.sg

YU Dan
Center for Management of Science and Technology,
National University of Singapore,
Singapore.
yudan@nus.edu.sg

CHAI Kah Hin
Department of Industrial and System Engineering,
National University of Singapore,
Singapore.
iseckh@nus.edu.sg

Abstract
Based on the rich debate over the theory of disruptive innovation in the literature, we first identify the technological dimension of disruptive innovation as a promising research area. We further propose that disruptive technologies can be challenging undertakings based on the in-depth analysis of two cases of disruptive technologies: Transistor radio technology developed in Sony and Inkjet printer technology developed in HP. The purpose of the above proposition is to call more attention to the study of technological dimension of disruptive innovation which can be well leveraged to create core competence for companies' future growth.

Key Words
Disruptive Technologies, Disruptive Innovation, Transistor, Inkjet Printer

INTRODUCTION
The disruptive innovation theory built by Harvard's Professor Clayton Christensen has created major impacts on management practitioners as well as aroused plenty of rich debates within academia. Professor Christensen's publications and the research followed by other scholars emphasized the key role of business model, leadership, and marketing, etc on commercializing products based on certain disruptive technologies; they did not further deliberate on the technological aspect of disruptive innovation. Yet due to the typical characteristics of low cost, simplicity and initial inferior performance, disruptive technologies may be misinterpreted as undemanding and unworthy task to do by established companies and researchers. Our research will address such a technological dimension. We hope to correct the above misperception on the technological aspect and to contribute to the potential of creating disruptive technologies on purpose.

LITERATURE REVIEW
Researchers have argued that Christensen's theory [1] suffers from limitations of ambiguity in the definition of disruptive technology [2]. Danneels suggested that several scholars seemed to think that Christensen did not provide a precise and consistent definition of the term disruptive technology [3]. People may misinterpret disruptive technology as any new technology that underperforms the dominant one in technical performance. Christensen coined the term "disruptive technology" in the bestseller "The innovator's dilemma" [1], but over time, Christensen widened the application of his theory to include not only technological innovation in products but also services and business models innovation. He thus focused more and more on "Disruptive innovation" [4] [5]. He has also looked at disruptive innovation phenomena through the lens of marketing [6]. Hence, it's clear that most of his research has been done on business models, marketing and management/ leadership issues. Furthermore, even for technological disruptive innovation, he used cases where a suitable disruptive technology was already available with certain desired characteristics, and focused on the process of implementation of disruptive innovation and other challenges in managing disruptive innovation.

In this paper, we will focus on the issue of technologies which is important in disruptive technological innovation but not addressed in-depth in the past. We define disruptive technologies as technologies which enable a product to have features suitable for it to be used in conjunction with the new business model that altogether leads to disruptive innovation. Of disruptive innovation lineage, disruptive technologies also should meet the specifications as follows [2]:

- The new technology initially underperforms the dominant one along the dimensions mainstream customers in major markets have historically valued.
- But the new technology has other technical performances that new or non-consumption customers value.
- Products based on disruptive technology are typically cheaper, simpler, smaller, or more convenient than those established on dominant technology

Some scholars and managers of established companies are still skeptical about the concept of disruptiveness because all of Christensen's examples are ex post with hindsight, and it is difficult to make ex ante predictions regarding a technology's potential and disruptiveness [7]. One possible reason is that many successful disruptive innovation cases in the past happened by chance or by intuition of the entrepreneurs. Instead of waiting for such opportunity which could easily draws other followers, one innovative strategy could be to develop disruptive technologies by purpose, for instance, by either simplifying or reshaping radical technologies into disruptive technologies or discovering inherently disruptive technologies ahead of others. Here, we follow the definition of radical technology given by Richard Leifer et. al [8]. They differentiate incremental innovation and radical innovation through a clear delineation of the technological features that are commercialized, either in existing market or new markets. Radical technology has the potential to produce one or more of the following:

- An entirely new set of performance features;
- Improvement in known performance features of five times or greater;
- A significant (>30%) reduction in cost.

Upon completion of purposeful disruptive technology development, the disruptive innovation theory can be fully applied. Cultivation of disruptive technology by purpose equips managers and CEOs with another tool for innovation and business growth. While many companies may invest in radical technologies, especially those inclined to do “technology push”, disruptive technologies are often ignored. They may also be regarded as “low-end” work and avoided by R&D departments. Although disruptive technologies are indeed simpler than radical technologies, they may still be a lot of technological challenges in their initial development. We shall study this dimension through two cases in the following sections.

METHODOLOGY

Given the lack of prior research focusing on the technological aspect of disruptive innovation, we shall use a grounded-theory building approach to explore challenges in developing disruptive technology. The research design is multiple-case, embedded study. In contrast to a pooled logic in which each observation is part of a larger sample, multiple cases enable a replication logic in which cases are treated as a series of experiments, each serving to confirm or disconfirm inferences drawn from the others [9].

The research setting is high-tech companies that consciously or unconsciously pursue the strategy of developing disruptive technology. We argue that from a technological perspective, such companies are better positioned than other kinds of firms to develop challenging technologies because of better R&D researchers, engineers and scientists, advanced facilities, favorable environments, wider technological social network, etc.

The two cases selected for this research are transistor radio versus vacuum tube radio developed by Sony and Inkjet printer versus laser printer developed by Hewlett-Packard. Our choices of the above cases are in view of the following four reasons: First and foremost, transistor technology and Inkjet printer technology were the typical examples of disruptive technological innovation illustrated in Christensen’s book [1]. Secondly, both transistor and inkjet are leading edge technologies of great importance to the development of the state of art in each field. New business model, branding, and leadership excellence by no means can substitute the core position of technology in these related products. Hence the cases further concentrate our study on technological aspect of disruptive innovation. Thirdly, Sony was the inventor of pocket-sized transistor radio which utilized all miniature components and won great success all over the world [10]. Competitors such as RCA pursued the radical innovation path and lost the battle. In the same vein, HP was the major supplier that dominated over 90 percent of the market for printers for printing technical drawings [10] that demonstrated its strong R&D capability in printing technology development. It was a dominant player in the laser printer market and yet it paid attention to the initially inferior inkjet printer. Therefore, they were both companies that pursue the path of disruption. Last but not least, the difference between Sony and HP helps to widen the general applicability of our argument that disruptive technology sometimes requires substantial efforts that is not straightforward. Sony first licensed the transistor patents from Western Electric [11]. But they soon realized that this was far from adequate and they then improved the transistor on dimensions such as reliability, cost reductions and material selection etc. Instead of possessing the basic transistor technology know-how like Sony, HP started to build the Inkjet printer from scratch. Although the starting points and the ways they developed disruptive technology were different, both of these cases would paint a clear picture of the challenging task in developing disruptive technologies.

CASE ONE: TRANSISTOR RADIO TECHNOLOGY VS VACUUM TUBE TECHNOLOGY—DEVELOPMENT IN SONY

Soon after Bell labs announced its success in building the first practical point-contact transistor at Bell labs in 1948, large incumbents of vacuum tube, such as RCA, GE, and Westinghouse all observed the threat of upcoming transistor and licensed in the transistor technology. In order to further improve the transistor technology to be good enough to replace vacuum tubes in the existing market of big tabletop radios and those big floor-standing televisions, they invested as a group, in today’s dollars, between $1 and $2 billion in R&D over 10 years. They thus pursued the radical innovation strategy which created an extremely difficult technological hurdle to surmount.

However, Sony went along the disruptive innovation trajectory and picked a simpler application—the portable transistor radio targeted at customers whose alternative was to have no radio at all. Although it was a simpler application, the project team made strenuous efforts after licensing the transistor technology from Western Electric. When Ibuka, the president of Totsuko (Tokyo Tsushin Kogyo, in English which means Tokyo Telecommunica-tions Engineering Corporation, the forerunner of Sony) went to the Ministry of International Trade and Industry of Japan (MITI) to obtain a license for manufacturing the transistor in Japan, MITI thought transistor could not be produced so easily and they questioned how such a small factory like Totsuko could produce such a complex thing as the transistor. Similarly, as Akio Morita said in his book "Made in Japan" [11]: "This solid-state device was something completely new to our experience", "it occurred to Ibuka that our company now had about one hundred and twenty employees, about a third of them graduate engineers and developing the transistor for our use would be a job that would challenge the skills of all of them.", etc. Many technical challenges were indeed encountered: the transistors were not reliable at that time; the material should be selected and improved to get the increased frequency they needed.

The early Bell labs transistor used a slab of germanium, the negative part, to which indium, the positive part, was alloyed on each side. After a period of intensive analysis, Sony team reasoned that since negative electrons moved faster than positive ones, they could get higher frequency by reversing the polarity. That meant replacing the positive-negative-positive configuration to negative-positive-negative, but they could not find the right material. Indium had too low a melting point for their purpose, so they began experiments using gallium and antimony, but it didn't work well either. At one point, everyone seemed stumped and they thought of using phosphorus to replace antimony. Unfortunately, they found that Bell labs had already tried this and failed. As Morita said, "It was very complicated work, and our project team went through a long period of painstaking trial and error, using new, or at least different, materials to get the increased frequency we needed." They even had to rebuild and virtually reinvented the transistor. Nevertheless, one team kept trying what was called phosphorus doping method, using more and more phosphorus in the process and finally succeeded at the end that greatly shocked the Bell labs scientists who gave up prematurely.

Furthermore, in order to fit the transistor and other electronics components into their small radio, they almost redesigned everything by themselves. Finding or designing parts small enough to fit together and employing PCBs were not easy at all. Almost every component required innovation. Hence, the team went around to individual component manufacturers and persuaded them to miniaturize components such as microphones, etc. In addition, how to develop the mass-produce capability of transistor to make low cost but better yield production were questions very tough to address.

A glance at the key members of the transistor development project could also help us understand how difficult this disruptive technology development could be. Dr. Leo Esaki had a Physics PhD degree from the University of Tokyo. He received various awards for his outstanding pioneering work and contributions to many areas in Physics; he also served on numerous international scientific advisory boards and committees. After the breakthrough discovery of tunnel diode during his transistor research in Sony lab which won his 1973 Nobel Prize, he went to IBM, and became Director of IBM-Japan, Ltd., and a member of the Governing Board of the IBM-Tokyo Research Laboratory [10]. Akio Morita, another physicist, was the co-founder of Sony Corporation together with Masaru Ibuka. With a deep technical background, he could understand and support the technical R&D needed to improve the transistor [11]. Masaru Ibuka graduated in 1933 from Waseda University where he was nicknamed "genius inventor". He co-founded the forerunner of Sony with Morita in 1946. He was instrumental in securing the licensing of transistor technology to Sony from Bell labs in the 1950s, thus making Sony one of the first companies to apply transistor technology to non-military areas [10]. While other companies saw no future in small transistor radios, led by the above great men with exceptional visions, Sony did made it into reality and later became one of the most powerful and respected multinational corporations in the world. Should the project be put into a group of more ordinary engineers without these outstanding scientists, engineers, as well as market champions, we might not be able to see the portable radio invented so soon after the invention of transistor.

Evidence from USPTO patent database further supports the above argument. Behind the initial great success of portable transistor radio TR-63 in 1957 and the continuing advancement for many years, 713 patents have been filed during 1958 to 2006. One patent with the title "Insulated gate field effect transistor" has been cited 110 times so far. Another 5 patents were highly cited with forward citation of over 50. There were 44 patents with forward citation of more than 20. Table 1 shows us the patent distribution of transistor technology filed by Sony from 1958 to 2006.

Examination from different perspectives boils down to the same result: The development of disruptive technology such as transistor can be an extremely challenging undertaking.

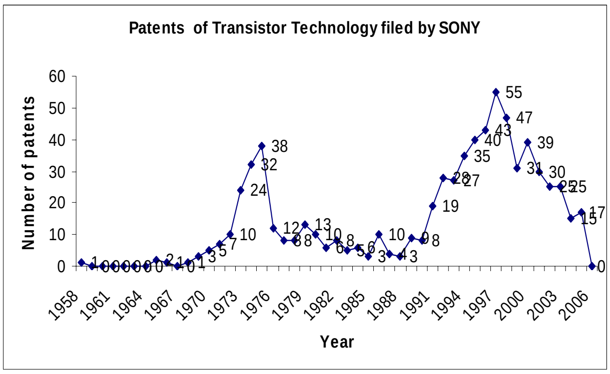

Figure 1 Patents of Transistor Technology Filed by SONY

CASE TWO: INKJET PRINTER VS LASER PRINTER—DEVELOPMENT IN HP

LaserJet, the revolutionary product with superior performance such as 300-dpi output, 8 pages per minute, commanded a premium price of $3459. In contrast, the industry's first mass-marketed, personal Inkjet printer from HP was a slow, messy machine which could offer only 96-dpi output at a print speed of 150 characters per second and a cartridge-swapping system of black, red, green and blue that could only be priced at $495. That was the story in 1984, when the thermal inkjet was no match for the laser printers in performance [12]. But eventually, the scrappy little inkjet printer got better and better and in 2002, the inkjet already could spit out crisp color pictures, sharp text and brilliant graphics as good as any laser printer costing 30 to 40 times more. The inkjet printer almost dominated the printing market and it outsold laser models twelve fold.

It was a typical hard-won victory of disruptive technology. Ever since 1951, when Siemens produced the first continuous inkjet printer in the world, throughout the 1960s, when other manufacturers unveiled improvements on the same idea, all companies have failed with little success. Inkjet proved expensive, messy and unreliable, with pumps, bladders and other moving parts that simply could not deliver an affordable machine capable of producing high-quality printers. There were other challenges with size, design, print heads, and varying paper quality that really called for extremely diligent and creative teamwork. When HP began to make efforts in 1978, there were two categories of printers: impact and non-impact. Non impact printers were far from mature but promised to be more accurate and efficient. Among over 5 non-impact technologies competing at that time, the team finally chose inkjet because of its far greater potential than rivals. Mr. Vaught, the leader of this project, focused on building a solid-state print head that would experience less wear and no clogging, but still be able to spit ink out fast enough for the job. Thanks to the enlightenment from a coffee percolator, he finally got away from bewilderment by realizing the answer was to use the ink itself to shoot dots on to paper. For the first time, he tried using a pair of electrodes with the ink between them acting as a resistor. A very small portion of ink near a nozzle would be heated to vaporize, and spit out as a droplet. Unfortunately, the ink did not have high enough resistivity to create the necessary heat. Even worse, the process electrolyzed some water in the ink into hydrogen and oxygen, which interfered with the operation. Mr. Vaught then tried another way by harnessing the hydrogen and oxygen to produce a micro-explosion capable of firing the ink out of the nozzle. A small spark could be induced across the electrodes to ignite the hydrogen bubbles and spit out a drop of ink, but the process was nowhere near fast enough. In the third attempt, the team opted to put all the energy into the spark itself, in order to boil a bubble of ink. But the electrodes quickly deteriorated. After many trials and errors, the thin-film resistors made the ultimate breakthrough due to their capability to produce enough heat to boil a bubble of ink and spit a dot out rapidly with a high degree of control. The resistor were mounted inside small tubes that were etched with grooves to create the nozzles and switched on and off rapidly to spit out microscopic dots of ink. It enabled HP to produce a workable version of a thermal inkjet mechanism.

In order to complete the entire product, many efforts were made one by one. The new quick-drying and light-fast inks had to be developed. Better mechanisms for feeding the paper, and new software to improve image quality were added. The speed was increased by making faster motors and lightening print-head mechanisms while increasing the number of nozzles on their heads. More features such as fax machines and copiers were added. The color printer dream was realized in the 1990s subsequently.

USPTO patent database has provided further supporting evidence. In order to develop a high performance and yet low-cost inkjet printer, HP has filed 309 patents since 1978 when the project initially launched, among which 5 patents were of great importance with forward citation of over 60, and there are 1,2,13,10 influencing patents with forward citation rate at 50-59, 40-49, 30-39 and 20-29, respectively. Table 1 shows us the patent distribution of Inkjet printer patents obtained by HP from 1978 to 2006. Among all these patents, the one with patent number 4490728 is the foundation of Thermal Inkjet printer. The title is Thermal ink jet printer and it enjoys forward citation of 279 so far, widely citied by Canon, Xerox, etc. Both the quantity of patents and quality of key patents that spur numerous innovations demonstrate the pioneering position as well as the difficulty within the development process.

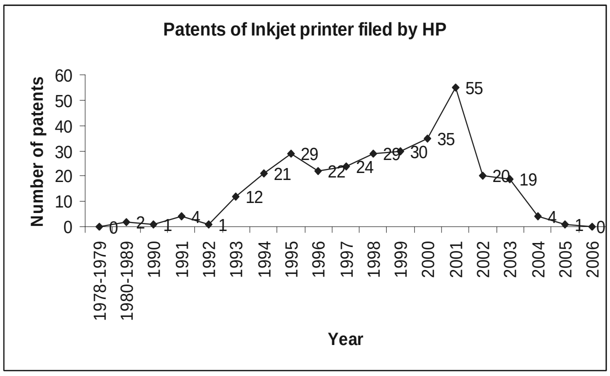

Figure 2 Patents of Inkjet Printer Filed by HP

DISCUSSION

Because of the simplicity, initial inferior performance and emergence in relatively insignificant markets, technologies in disruptive innovation could be disregarded as not very challenging. However, the above two cases have given strong evidence that they might not be as simple as incremental R&D as they were indeed discontinuous. Generally speaking, disruptive technologies could indeed be very challenging to develop on purpose. Fortunately, they are still simpler than radical technology which may cost 10 years, over 100 million dollars and more than 100 researchers for its development. Companies are advised to pay attention to the significant technological challenges in disruptive innovation, in addition to dimensions of business model and leadership. Technological barriers established by challenges of technologies within disruptive innovation could indeed be established and protected by patents, especially in hi-tech or knowledge-intensive industries.

Mainly based on leading-edge technologies involved in disruptive innovation, Sony made a series of successful disruption and became one of the world's largest media conglomerates. By means of technological disruptive innovation like Inkjet printer, Hewlett-Packard sustained prosperous growth by partially cannibalizing its own Laser printer business. While the entrants and the incumbents being disrupted were different in these two cases, the remarkable insights are identical: Disruptive technologies may not be low-end and undemanding technologies, and their difficulty mirrors the possibility and necessity to mark them as part of the core competences for the company. The more complex the disruptive technology, the more promising and longer future the disruptive innovation could be expected, and thus it makes more sense to keep it as core competence. Moreover, companies that pursue the disruptive innovation trajectory equipped with solid technological capacity can enjoy the first mover advantage to grab the largest piece of the cake. They also could rely on strategic patent filing to fend off competitions.

CONCLUSION

We have contributed first by identifying the technological aspect of disruptive innovation as a worthwhile research area which provides another lens for managers to create opportunity for sustaining growth. We also leverage two cases, transistor vs vacuum tube radio developed by Sony and Inkjet printer vs Laser printer developed by HP, to support the argument that development of disruptive technology could demand significant efforts and skills. Hence, companies should take the technological dimension of disruptive innovation more seriously in order to create the core competence for future development. Future research will be needed on how disruptive technology can be systematically developed in advance and also by purpose through simplification of radical technologies or exploration of the inherently disruptive technologies.

REFERENCES

[1] Clayton M. Christensen. *The innovator's Dilemma*. Harvard Business School Press, Boston, 1997.

[2] Gerarad J. Tellis, Disruptive Technology or Visionary Leadership. *The Journal of Product Innovation Management*, 23: 34-38, 2006.

[3] Daneels, Erwin, Disruptive Technology Reconsidered: A critique and Research Agenda. *Journal of Product Innovation Management*, 21(4): 246-258, 2004.

[4] *The Innovator's Solution*. Harvard Business School Press, Boston, 2003.

[5] Clayton M. Christensen, The Ongoing Process of Building a Theory of Disruption. *Journal of Product Innovation Management*, 23: 39-55, 2006.

[6] Daneels, Erwin, From the Guest Editor Dialogue on the Effects of Disruptive Technology on Firms and Industries, *Journal of Product Innovation Management*, 23: 2-4, 2006.

[7] Vijay Govindarajan and Praveen K. Kopalle, The Usefulness of Measuring Disruptiveness of Innovations Ex Post in Making Ex Ante Predictions. *Journal of Product Innovation Management*, 23:12-18, 2006.

[8] Richard Leifer, Chris McDermott, Gina C. *Radical Innovation*. Harvard Business School Press, 2000.

[9] Yin, R. *Case study research: Design and method* (1st edition). Beverly Hills, CA, Sage Publishing, 1984.

[10] http://en.wikipedia.org.

[11] Akio Morita, Edwin M. Reingold and Mitsuko Shimomura. *Made in Japan*. E. P Dutton, New American Library, 1986.

[12] *Twenty years of innovation: HP LaserJet and Inkjet printers 1984-2004*.