Managing technological innovation and sustaining competitive advantage in the digital imaging industry

by

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Abstract

The emergence and adoption of a disruptive technology that replaces an existing industry platform not only has enormous implications to incumbent firms, but also creates business opportunities that is enabled by the newly adopted technology. Firms competing in such an evolving and dynamic industry face great management challenges in its product's technological innovation process. Furthermore, defining strategies to sustain its competitive advantage through the market evolution by transitioning to the new platform is a non-trivial management task.

This thesis focuses on the digital imaging industry that consists of input/output/storage devices as well as related software and services. This thesis will

- describe the evolution, transition, and competitive/collaborative environment of the consumer photography industry, both analog and digital, by way of value chain analysis,
- identify current trends that is shaping the digital imaging industry and the challenges it faces,
- explore key factors that influence the expansion of digital imaging, focusing on two platform technologies, specifically the image data format and removable memory card format,
- discuss the strategic implications for a new format to be introduced in a fast growing industry and its diffusion strategies, and
- establish a basis to allow firms to address the industry challenges in order to sustain its competitive advantage.

Thesis Supervisor: Michael A. Cusumano
Title: Sloan Management Review Distinguished Professor of Management

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Chapter 1: Introduction

1.1. Background

Digital imaging has passed its fermentation phase from the early 1980's to the early 1990's and have quickly taken off to a rapid growth period following the steep product life cycle S-curve in the late 1990's continuing on in the early 2000's. While there were many high-growth projections being made during this launch phase for digital imaging, particularly in the digital still camera (DSC) category, people still questioned whether it can and will replace the conventional film business arguing primarily of low-quality images and high prices. However, once a dominant design emerged for a DSC, a marriage of matured film-based technologies and consumer electronic parts, incremental innovation that focused in key components such as image sensors and signal processing had allowed the cameras to advance its image quality, performance and reduce its relative price compared to prior models. This combination of photography and consumer electronics changed the experience of taking a picture and attracted both novice as well as serious photographers.

The advancement of digital imaging technology has not only become a disruptive force for the conventional photographic experience but also created new opportunities that had not been possible, or a least not as easy as, with film-based photography. While the fundamental experience of photography for the user essentially remains the same, the images are now already digitally captured and stored in memory attached to the camera, therefore the critical process in film-based photography, film development, need not be done for the picture to be viewed, shared or printed. Due to this fact, the photography industry has transformed/expanded into the consumer electronics (CE) market creating new opportunities for firms already competing in the CE industry; conventional photography firms that have embraced digital technology are also facing challenges to sustain its competitive position in this new, dynamic industry.

1.2. Motivation and Scope

As technology in an industry evolves, either incrementally or radically/discontinuously, the nature of the competition inevitably changes. In some cases, the changes are modular in that the firm's existing resources such as brand, distribution channels, and technical expertise including manufacturing capabilities can still be effectively utilized given that appropriate organizational and technical adaptations are made. However, there are cases where the fundamental technology is replaced, which often are the revenue-generating business of an incumbent firm, and therefore a more drastic transformation is required to sustain its competitive advantage. The photography industry is such a case where the conventional film business is being disrupted and replaced by digital technology forming a new industry commonly referred to as "digital imaging."

This thesis is to identify means to expand the application of digital imaging beyond the current state, primarily driven by DSC sales, by examining two key technologies that can play an important role in creating opportunities and increasing utilization of digital imaging: image file data format and removable memory card. Both technologies relate to the portability and transferability of digital images, hence affects the application and opportunity of industry expansion. The key questions this thesis attempts to address are as follows:

- What are the success factors for digital imaging to date? What can be inhibiting its growth?
- What are challenges that the digital imaging industry face? In what way should the industry players respond in order to sustain the growth and utilization of digital imaging?
- What are the lessons to be learned from the conventional film photography industry that are applicable to the digital imaging industry?
- If there are solutions to the problems the digital imaging industry face, what are the strategic alternatives to realize such a solution?

The general term “photography industry” as a whole is quite broad where it can be categorized into two major segments: ‘consumer’ and ‘professional’. However, the separation of the two segment is not discrete but rather vague from a product perspective and should be considered a continuum as high-end consumers, a.k.a. prosumers, do exist which has strong interest in equipment that are by and large designed for professional use. The primary focus of this thesis will be on consumer photography, although we may consider professional photography issues as appropriate.

1.3. Structure of the Thesis

Chapter 1 is the introduction forming the basis of this thesis. Chapter 2 includes a review of relevant research on general frameworks capturing industry evolution and its dynamics among competitors, particularly when radical innovation occurs. The process and factors that affect how the technology becomes dominant is outlined. Chapter 3 reviews the evolution of the consumer photography industry with an emphasis on digital imaging. In addition, we examine the “photography value chain” contrasting conventional film photography with digital imaging. In Chapter 4, we present various industry trends of consumer photography in conventional film photography as well as digital imaging. Then in Chapter 5, we analyze the transition from analog-based conventional film photography to digital photography and identify current challenges that the digital imaging industry face today. Furthermore, we conduct a hypothetical technology transition scenario to gain insights on the strategies to address the challenge of industry expansion. Finally, we conclude the thesis in Chapter 6 by summarizing the findings in the previous chapters.

1.4. Terms

The following abbreviations are used throughout this thesis.

APS: Advanced Photo System

CCD: Charge Coupled Device

CD: Compact Disc

CE: Consumer Electronics

CIPA: Camera and Imaging Products Association

DCF: Design rule for Camera File format

DNG: Digital Negative

DSC: Digital Still Camera

DVC: Digital Video Camcoder

DVD: Digital Versatile Disc

Exif: Exchangeable Image File format

HDD: Hard Disc Drive

IP: Intellectual Property

ISO: International Organization for Standardization

JPEG: Joint Photographic Experts Group

LCD: Liquid Crystal Display

MP: Mega Pixel

PC: Personal Computer

PMA: Photo Marketing Association

SLR: Single-Lens Reflex

TIFF: Tag Image File Format

Chapter 2: Relevant Research

2.1. Technological Discontinuities

The accelerating pace of technological change is generally recognized, especially in the information technology industry, where firms must deal with a continuous stream of technological discontinuities. A technical discontinuity occurs when one technology is replaced by another, which is often shown as the gap between two S-curves as shown in Figure 2-1. (Foster, 1986) As such, the issue of how to recognize and adapt to these technological discontinuities is an increasingly important managerial challenge. (Anderson and Tushman, 1990, Christensen and Rosenbloom, 1995).

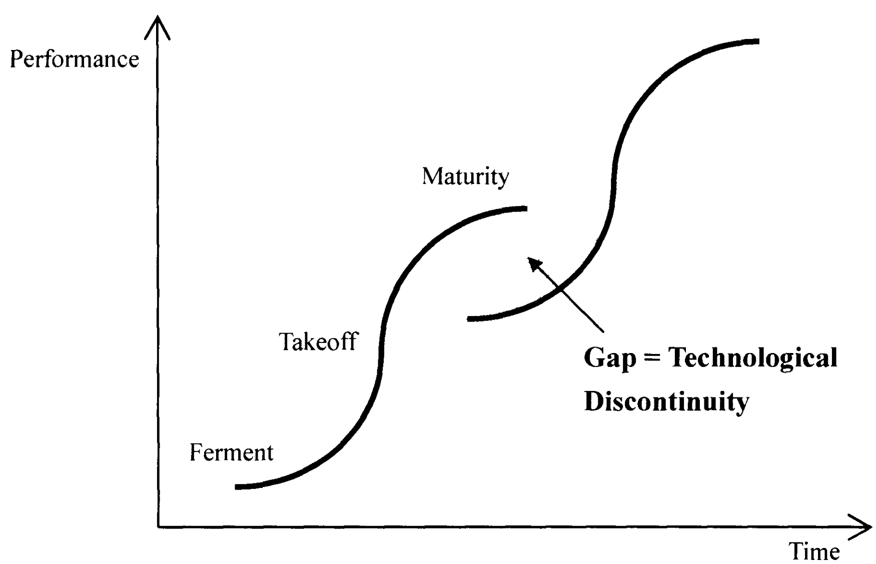

Figure 2-1: Technology S-Curve and Technological Discontinuity

Technological discontinuities cause a period of ferment where alternative technology or product forms compete for dominance in the market. One reason for having such an unstable and experimentation period is for the need to reduce the uncertainty of a new technology, both for the manufacturers and for the users, and to gain market acceptance; this, in effect, is the required time for testing. The length of such period is dependent to the industry and particular technology, however. During this period, innovation is relatively rapid; production processes must be highly flexible in order adapt to this high turnover. However, the experimental innovation period typically ends with the emergence of an industry standard or dominant design. (Anderson & Tushman 1990, Utterback 1994) These lead to cost reductions through economy of scale as well as increase in performance due to optimization. Once a standard or dominant design is defined, the competition changes from technology or product to process innovations which include the development and effective use of complementary assets such as manufacturing capabilities, marketing, and distribution channels. (Abernathy and Utterback, 1978, Christensen and Rosenbloom, 1995, Tushman and Anderson, 1986 and Utterback, 1994)

Once a dominant design is formed, it becomes difficult to overturn or replace it unless a new disruptive technology emerges. If the particular innovation has an impact on a large, complex system with interdependent subsystems, a significant technology change may make a component incompatible with the rest of the system and as such lead to a conclusion that the innovation is not feasible. Basic technological innovation affects the industry that is primarily introduced and other related industries that either build on or complement the industry where the innovation had occurred. (Tushman and Anderson, 1986)

One of the issues of technological discontinuity is that it creates short term uncertainty both for manufacturers as well as consumers as they are unfamiliar with the emerging technology; time may solve this but must be resolved before widespread adoption can happen. From the incumbent firm's perspective, the new characteristics of the technology may destroy its existing competences; this forces existing firms to either adapt to the new technology in order to continue competing in that industry or exit it. Furthermore, the new technology may be incompatible with other components of complex systems of which it is a part of. As such, the new technology may change the balance or dynamics of the existing business relationship that evolved around the old technology and its complements. If these issues are not properly addressed, there is a risk of consumers resisting the adoption of the new technology.

2.2. Battle for Technological Dominance

During the fermentation era following a technological discontinuity, battles for technological dominance occur. Suarez (2004) proposes an integrative framework to understand the process and factors that influential how a technology becomes dominant.

2.2.1. Factors affecting Technology Dominance

Key firm- and environment-level factors that affect the outcome of a battle for technological dominance is shown in Figure 2-2.

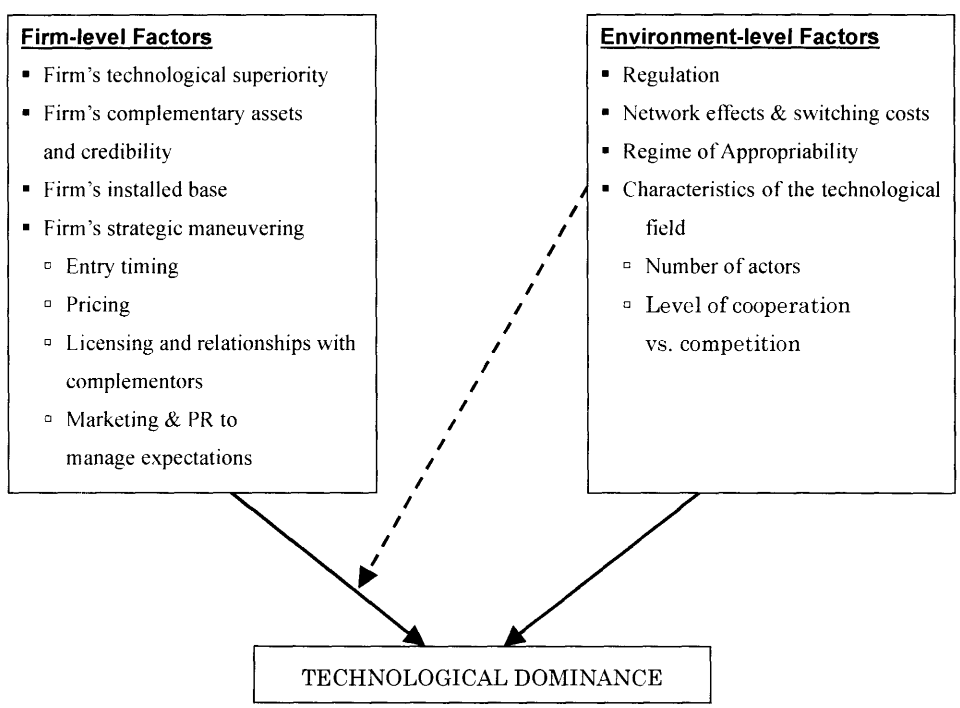

Figure 2-2: Firm- and Environment-level Factors Influencing Technology Battles

In this framework, four firm-level factors are identified. The first is *Firm's technological superiority.* This factor deals with how superior the firm's technology performance is compared to competing alternatives. It is important to note that technological superiority alone cannot be considered a major factor unless there are very significant performance differences between the technology and competing alternatives. The second is *Firm's complementary assets and credibility.* In addition to 3rd party products, internal resources of a firm, such as manufacturing capabilities, are considered as complementary assets. Credibility is primarily the reputation of the firm within the relevant industry where the technological battle takes place. The third factor is *Firm's installed base size.* When a firm has a larger installed base in comparison with its competitors, it creates a positive reinforcing force that increases the attractiveness of a specific technology that the firm is providing. A firm's strategy to be compatible with existing widely deployed technology may also fall into this factor. The fourth factor, *Firm's strategic maneuvering*, four key elements for firm's strategy in a technological dominance battle: the timing to enter a market, the pricing policy, the relationship with complementors which includes licensing issues, and marketing efforts to stimulate the market.

There are also four environment-level factors that influence the dominance battle. *Regulation* is the first factor. These are governmental or institutional intervention which includes regulation, government requirements for procurement, and formal standardization. The second factor is *Network effects and switching costs.* Network externalities where the value or utility of a technology to a potential user is dependent on the total number of customers already connected to that network. This relates but is not limited to the firm's installed base. Switching cost can be either actual cost incurred when changing from one technology to another where new investments are needed, or implied cost that deals with intangible assets that may not translate into a monetary figure. Once a customer is locked-in to a particular technology or service, it is very difficult for competing technologies to replace.

The third environmental factor is the *Regime of appropriability* that governs a firm's ability to capture the profits generated by an invention. (Teece 1986) The important dimensions of such a regime are the nature of the technology (i.e. product or process) and the efficacy of the legal system for protection (e.g. patents, copyright, and trade secrets). The final factor is *Characteristics of the technological field* which is the industry's structure, such as the number of competitors, and dynamics within the field relevant to the technology.

2.2.2. Technology Dominance Process

In addition to the factors, a five-milestone process is defined. The dominance process is divided into five phases where each milestone is a transition from a particular phase to another. (See Figure 2-3)

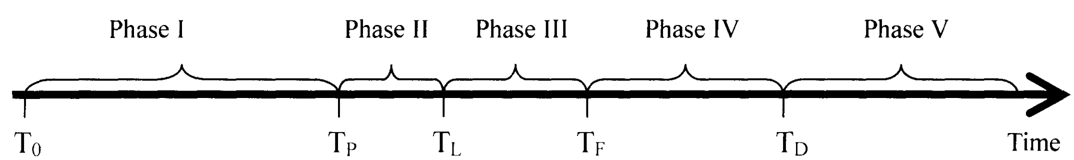

Figure 2-3: Five milestones in the Technological Dominance Process

According to Suarez, the first phase, Phase I (T_0-T_P), is termed *R&D buildup*. In this phase, key characteristics of the technological field are evaluated. Those technologies that meet those criteria will move on the next phase, Phase II (T_P-T_L), which deals with *Technical Feasibility*. Prototypes are developed in order to check and prove that the technology is viable. Phase III (T_L-T_F) labeled, *Creating the Market*, is where the technology is introduced in the first product launch. At this phase, new alliances are secured to support complementary products or services. The next phase, Phase IV (T_F-T_D) called *Decisive Battle*, is where the visible battle takes place. Competitors introduce products based on alternative and/or improved technologies each party accumulating its own installed base of users. The final phase, Phase V (T_D—), *Post-dominance*, is the phase where the dominant technology is established in the market and the competition shifts toward process innovations such as improved manufacturing capabilities.

While this process is useful to examine each phase of the battle of technological dominance, it seems important to note that the phases can be iterative as well as overlapping. For example, even though a prototype may emerge signaling the transition to Phase II, firm level factors such as a licensing issue may force the phase to revert back to Phase I.

Chapter 3: Consumer Photography Industry

3.1. Overview

The history of consumer photography dates back to the early 19th century. When George Eastman invented a new picture-taking system with a roll-based film, this became the dominant design and de facto standard for consumer photography due to its simplicity and convenience. (Utterback, 1994) Many complementary products, including the camera, had evolved to support the fundamental desire of human nature: capturing the moment for one's memory.

Even though many incremental innovations on the film itself had occurred till fairly recently,[1] the fundamental process of photography from the end user's perspective has not changed: purchase a roll of film, set it in a camera, take pictures, have the film developed and then printed. Furthermore, since the film photography industry's infrastructure, both film distribution channels and film development lab, is well established, this photography experience is now globally supported. Consumers can buy a roll of film virtually anywhere in the world, install it in his or her film camera to take pictures, have the film developed, printed and returned in an hour or so at any location convenient for them.

The primary reason for such an ease of use can be attributed to the standardized size of the film itself and the film canister. Any film camera conforming to those specifications can be used to take pictures; any retail print shop can develop those films and print the pictures to satisfy the customer's needs. From the consumer's and manufacturer's point of view, this was a win-win situation creating value for both: convenience and satisfaction for the former, and economy of scale and steady revenue from repeated usage for the later. For the film industry in particular, this was a lucrative business model until the

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[1] An example is Fujifilm's "Fourth Color Layer Technology" introduced in the late 1980's. <http://www.fujifilm.ca/CorporateInfo/Default.asp?ParentID=7&SectionID=87&SID=90>

digital imaging era had emerged.

3.2. Dawn of Consumer Digital Imaging

The commercial interest in capturing a scene electronically, which evolved to become the basis of digital imaging, had begun in the early '80s when Sony had first prototyped a camera using a CCD (charge-coupled device) to capture a picture and storing the data on a magnetic disc drive. While a few products were in existence at that time, the key components were still costly up until the mid-'90's so it was only targeted to professional users who could afford the exceptionally high price. As such, it was difficult for firms to practically develop a consumer digital photography market. The breakthrough occurred when Casio released a product, QV-10, in 1995 (retail price at 65,000 yen) as it defined the basic style and function of a consumer DSC by adding a LCD monitor for instant viewing of pictures taken. This was a great commercial success and became the dominant design for DSCs. By adding a LCD monitor on the DSC for instant viewing, it cultivated a whole new consumer market segment apart from the traditional/conventional camera users: DSC also became a "communication device."

Figure 3-1 analyzes of the digital imaging industry using Porter's five force analysis at the time when the dominant design had emerged. For firms with existing resources either in photography or consumer electronics, the digital imaging market was attractive. Conventional film camera manufacturers saw this as a new growth opportunity to its stagnated camera sales business; consumer electronics firms considered this an opportunity to expand its product offerings linking DSC to their existing products such as TVs. Even though film manufacturers knew this would eventually be a threat to their existing film business, they could not risk being left behind the bandwagon.

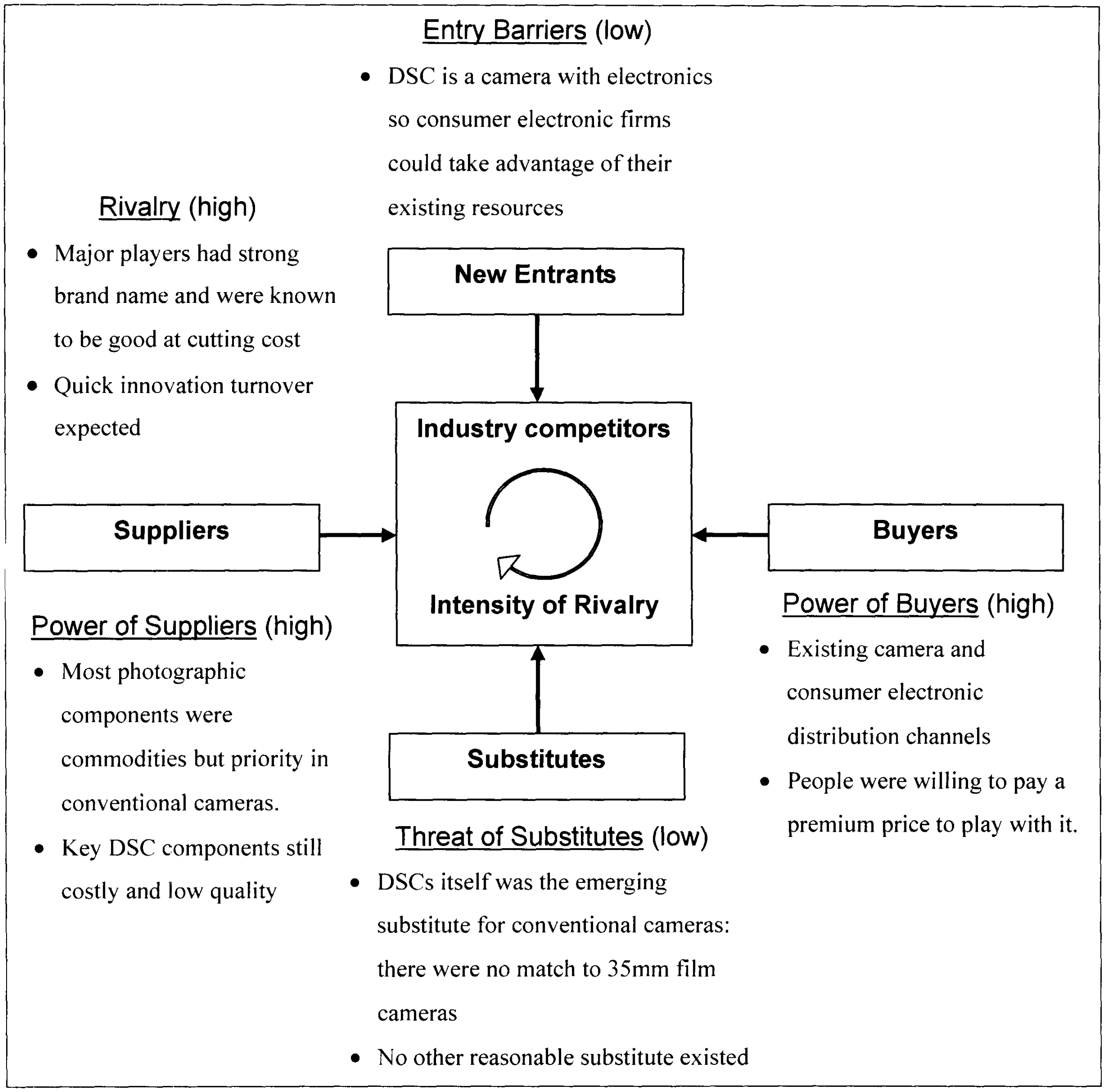

Figure 3-1: DSC Industry Analysis in the mid-'90s

Note that Porter's model is missing a very important player in the DSC industry. The wide acceptance of DSCs could not be explained without considering the existence of complementors, specifically the personal computers (PC), application software for viewing images, and the Internet. In addition, the DSC industry as a whole had played a unique roll in the proliferation of the DSC market hence expanding the digital imaging industry. At first, when the DSC market was still emerging, the leading manufacturers were quickly seeking to "lock-in" users to their own product by defining proprietary formats such as digital image format and data storage media that would force customers to use the products that that firm could only provide. This was in fact a standard practice in the conventional film camera industry where the interface to accessories such as the lens mount was proprietary. However, they soon realized that penetrating the mass customers in this direction was difficult as users were not interested in such a lock-in, particularly in platform technologies such as the image data format.

Hoping to further expand the market and its sales, DSC manufacturers, which were dominated by Japanese firms, joined forces as a committee in an industry association[2] to address several non-controversial technical issues that they saw as a benefit to the end user and themselves. The key enabling standard was the image data format "Exif." The Exif standard stipulated the data compression method, color technology, and data format for camera feature information (e.g. shutter speed, F-number). Not only was this a benefit to the DCS manufacturers but also was important for the complementors as well. Defining a standard image data format, it eliminated the need for software applications to keep track of the new developments of various DSC manufacturers and allowed them to focus on enhancing the user's experience. This also allowed various DSC firms to reduce its R&D costs leading to economic of scale for relatively costly key components image processors, and shift their development focus to innovate on non-standard features (e.g. image quality, usability) to differentiate each product. The image data format standard effectively became the "interface" for DSC complementors. After a dominant design of a DSC had been defined, many electronic component innovations were driven by the consumer electronics industry such as image sensors, particularly the CCDs, and electronic components, including LCD monitors.

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[2] At that time, it was JEIDA (Japan Electronic Industry Development Association), now called JEITA (Japan Electronics and Information Technology industries Association).

3.3. Photography Value Chain

Photography is considered an industry as a whole where several categories of products exist, such as the film and camera. From a consumer's point of view, it consists of a value chain with several relevant industries interconnected. The photography industry's value chain can generally be categorized into four phases as shown in Figure 3-2. Iteration between these phases does occur, for example from Storage back to Fulfillment for reprints, but typically follows the phases in sequence.

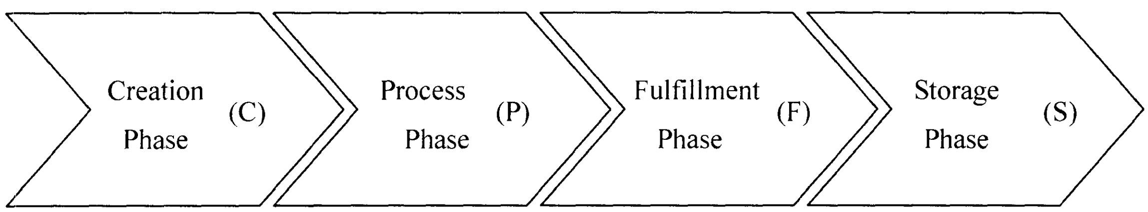

Figure 3-2: Value Chain for Photography

Creation Phase

The Creation Phase (C) is when the user takes a picture to record the moment. Relevant industries are cameras and the recording media. For conventional photography, the media is a roll of film, 35mm[3] or 24 mm APS[4], and for digital imaging, it is typically the removable memory card (See Appendix B for a list of removable memory cards used in DSCs).

This phase generally has two customer segments: consumer and professional. The consumer market can further be segmented as quick and easy, casual/hobbyist, prosumer/high-end amateur. The description of each segment and typical use are shown in Table 3-1.

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[3] The formal International Standard is ISO 1007:2000.

[4] Jointly developed and licensed by Canon Inc., Fuji Photo Film Co., Ltd., Eastman Kodak Company, Minolta Co., Ltd., and Nikon Corporation.

Table 3-1: Capture Phase Customer Segment

Customer Segment	Description	Film Camera	Digital Camera
Quick and easy	Quick and easy shooters; image quality and camera specific features not so important; style important	Compact camera with minimum settings Single-use film camera	Small/thin compact Add-on to other device (cell phone)
Casual/Hobbyist	High image quality; flexible camera settings	Compact camera with settings Low-end SLR camera	Compact camera with settings Low-end SLR camera
Prosumer/High-end armature	High image quality, lens options, simple image/color editing	SLR camera	Mid- to high-end SLR
Professional photographers	High image quality, durability, lens options, sophisticated image/color editing	Professional camera	High-end SLR

Process Phase

The Process Phase (P) is where the recorded data is converted into a state where the recorded data can be visualized. For conventional photography, the relevant industry consists of film development equipment manufacturers, and photo kiosks or print shops that accept print orders. For digital imaging, this process is usually completed in the DSC prior to converting the image sensor signals into a digital data format called Exif which uses JPEG compression[5]. (See Appendix A.2 and A.3 for an overview of Exif and JPEG technology, respectively) Alternatively, in order to serve the need of the professional and higher-end of the consumer market segment which requires high level of flexibility in adjusting the digital data, this phase would occur in the computer where the data is 'developed' into a visual form by software applications either provided by the DSC manufacturers or third party imaging software vendors such as Adobe using a plug-in to read the DSC's proprietary data format.

[5] The formal International Standard is ISO/IEC 10918-1|ITU-T T.81

Fulfillment Phase

The Fulfillment Phase (F) is the visualization of the moment, e.g. printout or viewing on a monitor, where the user can enjoy and share the image with others. For conventional photography, the relevant industry is the same as the Process Phase as most development equipments are also connected with a printer that converts the film to actual print. This is a mandatory process coupled with the Process Phase which closes the loop for film manufacturers to generate additional revenue from the films they sold.

Digital imaging, on the other hand, has many alternatives. The first and immediate fulfillment is the capturing device's monitor. The capture device can also be connected with a TV via analog cable for viewing. Furthermore, because the camera-recorded digital file uses the standard JPEG compression, any viewer or application that can display JPEG images can be used to view the images such as a PC or DVD player. An added benefit of digital imaging is that the images can be easily shared with friends and families either by email or using photo-sharing web sites. The various fulfillment methods can utilize existing devices or infrastructure turning them into complements of a digital imaging device expanding the scope of the digital imaging industry which is the source of new opportunities.

Storage Phase

The Storage Phase (S) is where the visualized moment is stored where it can be re-viewed at a later time. For conventional photography, both the film and printout would be stored but the primary focus is on the printed material. Selected printouts would typically be displayed in a photo stand or stored an album; others dumped in a shoebox. This essentially is the same for digital imaging, if the data were to be printed out. The digital data, on the other hand, will be stored on a hard disc drive (HDD) of a computer, copied to an external recording media such as a CD or DVD, or may be left in the removable memory card.

Chapter 4: Trends of the Photography Industry

4.1. Conventional Film Industry Trends

The total film sales reached its peak in the U.S. in year 2000, and since then, the total sales have continued to decrease. While single-use camera sales steadily grew over the years by cultivated a new market segment of the ultimate quick-and-easy photography, eliminating the need for a camera, it was not able to help stop the overall decline in total film sales. (See Figure 4-1)

Seeing the potential threat of digital technology eroding the photography industry in the early '90s, conventional film manufacturers began actively investing in the digital domain. However, they could not project how fast the pace of innovations for digital imaging would be to threaten their existing film business, and how quickly the film industry will be taken over. Film manufacturers are moving its manufacturing operations to lower cost markets in order to be cost competitive, and at the same time, shifting consumers to higher value films[6] but this is not a sustainable solution.

This trend of film sales decline can also be corroborated by the fact that major camera manufacturers has shifted its resources from analog to digital technology in year 2001 where firms are either exiting the market[7] or focus on high end products primarily for professional use. (See Figure 4-2)

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[6] Source: Eastman Kodak Company, Annual Report 2003

[7] Eastman Kodak announced that they will exit from the film camera business. (January, 2004)

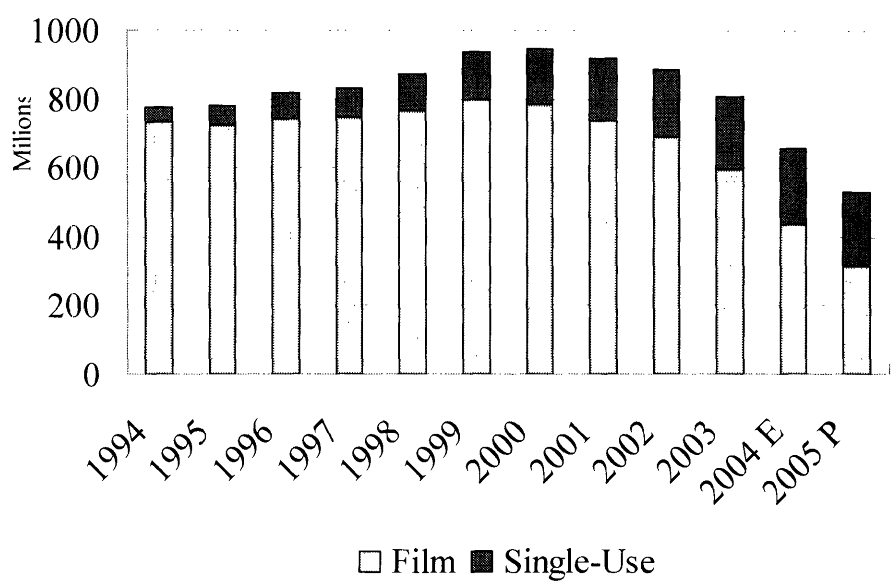

Figure 4-1: Film and Single-Use Camera Sales[8]

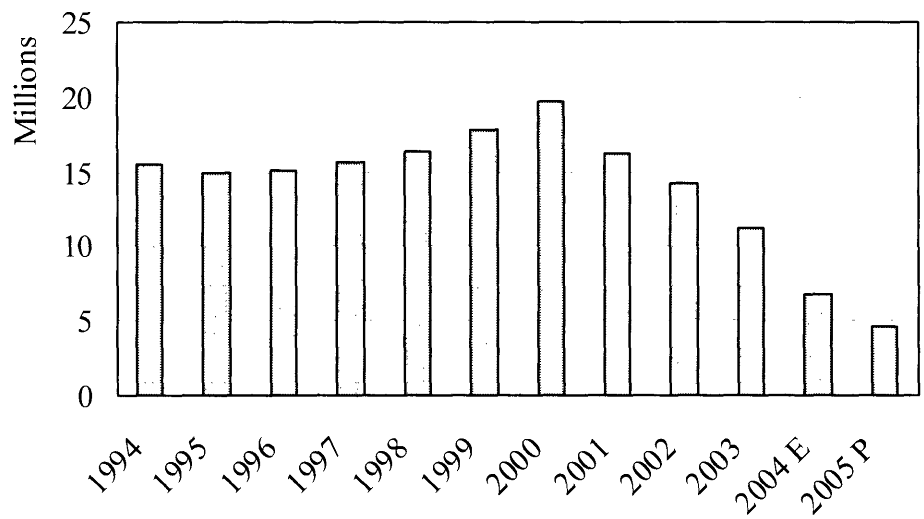

Figure 4-2: Analog Camera Sales[9]

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[8] Source: Photo Marketing Association International, "Photo Industry 2005: Review and Forecast", 2005

[9] Source: ibid.

4.2. Digital Imaging Industry Trends

4.2.1. Overview

Digital imaging for the consumer is a relatively new way of capturing and enjoying photography. In contrast to conventional photography, which is chemical-based analog, digital imaging captures the data electronically and stores the data in a digital form. This new method has huge implications to conventional photography firms: film rolls are replaced by the removable memory cards, films are replaced by image sensors embedded in the camera and digital data are stored in the removable memory card, photographic prints are being made at home instead of bringing the data to the print shop, and digital data can be viewed on a monitor without being physically printed on paper—the human culture of photography, or its process, is disrupted.

4.2.2. DSC Trend

DSC had been one of the hottest consumer electronic devices in recent years. It enjoyed a 50% annual growth, on average, for the last five years. However, as the market became mature and alternative devices had emerged, the growth rate is projected to decline.

As shown in Figure 4-3, over the past six years the DSC shipment had a rapid growth rate but recently show signs of stagnation. Average DSC unit price in year 2004 has also dropped approximately 60% compared to year 1999. Also, the data from year 2003-2004 in Figure 4-4 shows that the trend in growth decrease continued.

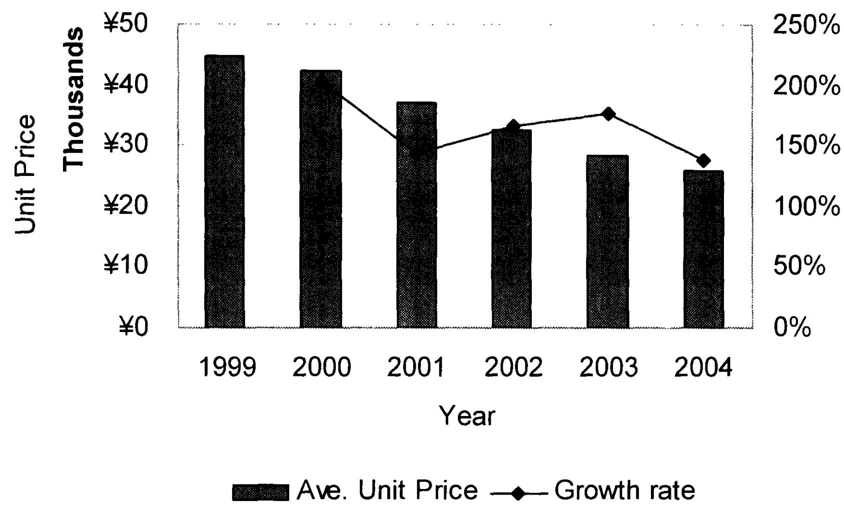

Figure 4-3: DSC Average Unit Price and Shipment Growth rate[10]

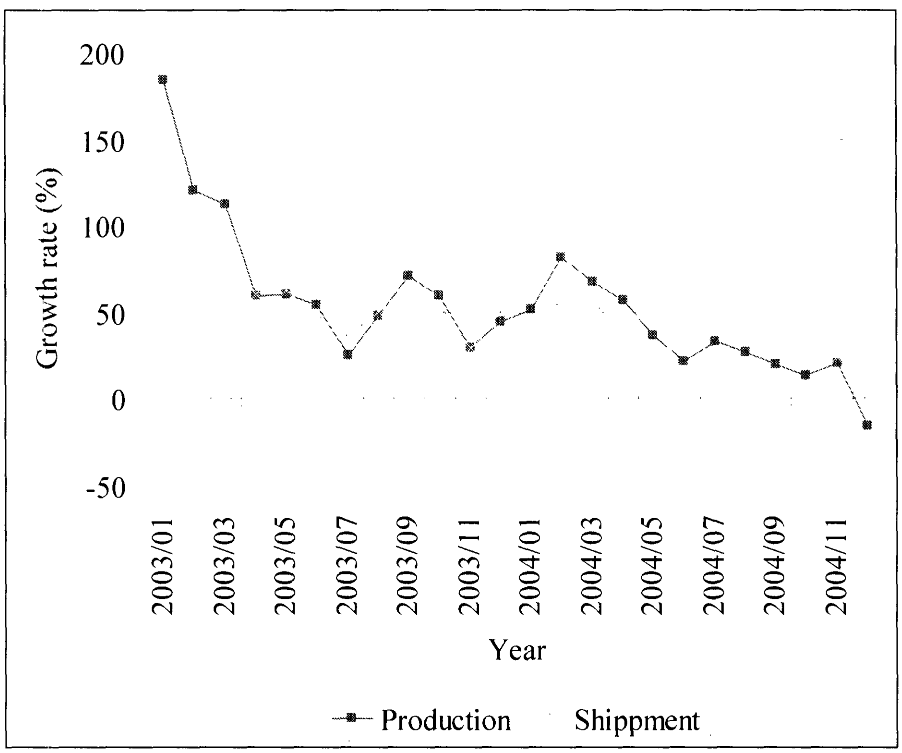

Figure 4-4: DSC Production and Shipment Growth (2003 – 2004)[11]

[10] Source: CIPA statistics (http://www.cipa.jp/english/data/dizital.html)

[11] Source: ibid.

From the recent trend in the DCS industry, several observations can be made. First, the transition to higher resolutions is a clear indication by camera manufacturers to mitigate the commoditization and pricing declines in the low end DSC models.[12] Second, while pixel count of the image sensor had been considered an important measure and differentiator of a DSC, being associated with an important factor of image quality, the current trend is for DSC manufacturers to market and compete with other features such as overall design (e.g. style and ease of use), image processing engines for image quality and speed (e.g. Canon's DIGIC), lens specifications (e.g. optical zoom or aperture range), and other functionalities (e.g. image stabilizing technologies).[13] This is a sign of industry maturity after a dominant design of the DSC had been established in the mid-1990s followed by the take-off period in the early 2000s.

Trajectory of DSC Innovation

Because of the projected decrease in the growth rate, DSC manufacturers are quickly shifting its product line into the higher quality category in order to maintain higher margin and to continue stimulating consumer's interest in DSCs, including repurchasing, because the latest version is functionally superior in many aspects not only in image quality but also response speed of the device, usability, and connectivity with other imaging devices. The general DSC market trend relative to the target quality level is shown in Figure 4-5. The ultimate image quality target for DSCs is to achieve the equivalent or even better quality compared to conventional film

[12] For example, KonicaMinolta, a prominent DSC manufacture, announced that they will focus on SLR type DSCs.

[13] While there are many adaptations of conventional film camera technologies to a DSC, there are many new innovations being made because of the use of digital technology.

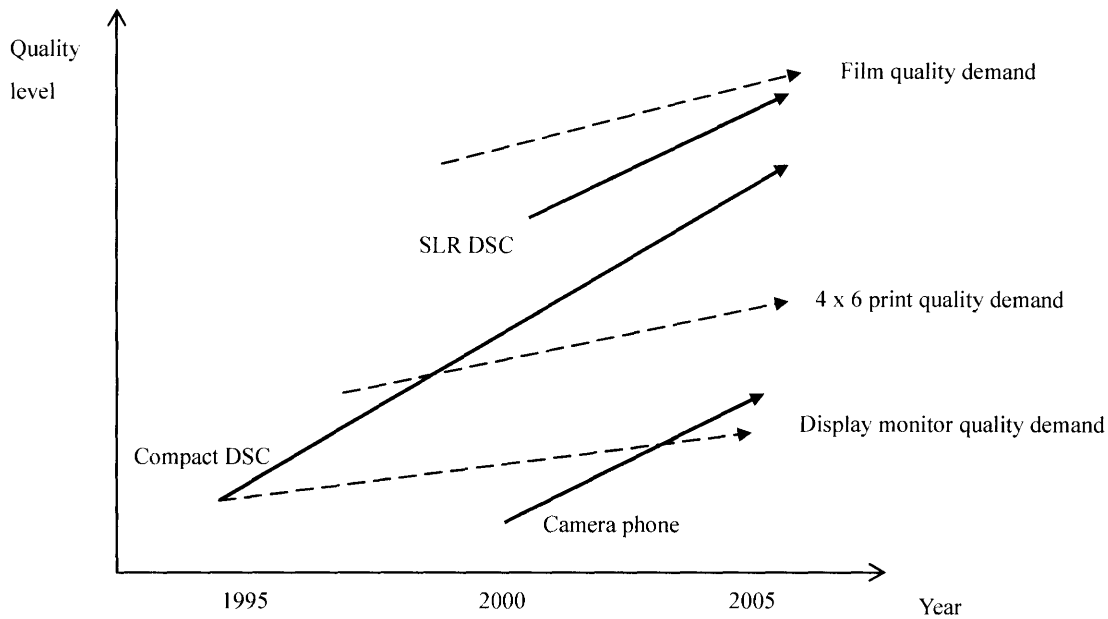

Figure 4-5: Trajectory of Innovation of DSCs

Higher Resolution

While the growth of sales of DCSs is decreasing, the portfolio of models being sold is rapidly shifting toward higher-end products where cameras equipped with image sensors with more than 5 MPs account for nearly 50% of the total DSC shipment. However, the lower resolution DSC did not disappear from the industry: it is now the dominant resolution for camera phones where more than 90% of the DSC components are less than 2MP.[14]

[14] Source: InfoTrends' 2004 Worldwide Camera Phone and Photo Messaging Forecast.

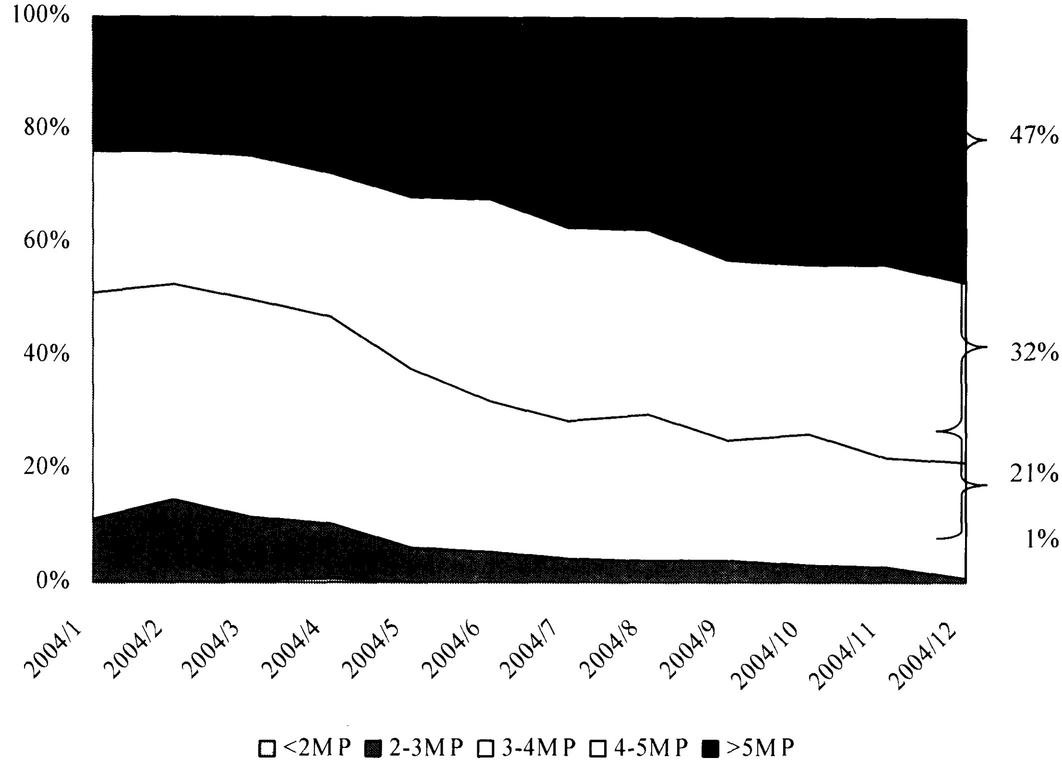

Figure 4-6: Trend in DSC models by Pixel Count[15]

Another aspect to examine is the quality level of the images of a DSC and its trajectory, as shown in Figure 4-5. Given that a DSC with at least a 2-3 MP, which now consists of nearly 100% of the total shipment, will produce sufficient 4x6 size printouts, camera phones are taking over the initial value proposition of DSCs which led to the explosive adoption: quick-and-easy image communication tool of casual capturing and on-the-spot sharing.

Larger Image Data

One major reason for DSCs to increase its sensor resolution is to capture more data of the scene by increasing the granularity of the sensor for higher quality images. One consequence of this trend is that

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[15] Source: CIPA statistics (http://www.cipa.jp/english/data/dizital.html)

the data size per captured image increases. As noted previously, the standard image file format for DCSs is Exif which uses JPEG compression; Exif files can be easily transferred and viewed on a PC or any device capable of decoding and rendering a JPEG file. However, a 4MP DSC at maximum resolution with low compression, i.e. high-quality setting, will produce an image data file that is approximately 2MB.[16] The closer the DSC image quality target reaches the film equivalent, the larger the image data will be. Even though JPEG is well-known as being a very efficient image compression technology, if the source data itself increases significantly the compressed data size will still be large, especially to maintain high quality images.[17] Larger data size requires larger capacity in removable memory, more time to write data in a storage media, and more bandwidth required for rapid data transmission.

RAW Image Data

JPEG compression is a lossy compression technology where high frequency signal data are discarded and generates blocking artifacts. For higher-end consumers and professional photographers, this causes problems particularly when the image is enlarged where a so-called block artifact becomes visible reducing the quality of the image. In order to address this issue, and to allow flexibility in image data manipulation such as color correction by the user, mid- to high-end DSC supports an optional output data format, typically called CCD RAW file or simply RAW image. This RAW image is the data generated by the image sensor and stored on the removable memory card without being processed. Unlike in the case of Exif files, any interpolation of the image sensor data and adjustment of camera setting parameters can be controlled by a software application on a PC. The benefit of this process is that the photographer

[16] An uncompressed file would be approximately 11MB. (where 2272(w) x 1704 (h) x 24 bit color = 92,915,712 bits = 11,614,464 byte/1024/1024 = 11.0MB)

[17] By increasing the compression ratio, the file size can be reduced at the cost of significant loss of image quality.

has manual control over the camera settings which has direct affects on the image quality; they can also choose the final output/storage data format such as JPEG or TIFF. Although there are many technical benefits in RAW data from an image quality perspective, there are also drawbacks: the data format is proprietary and manufacture dependent having implications to existing digital imaging workflows. All DSC manufacturers that generate RAW image data provide their own software application that enables user to read and manipulate the RAW image data taking advantage of the proprietary knowledge of each DSCs.[18] This is a potential threat to existing imaging software application vendors.

Seeing this as an issue, Adobe Systems announced a specification in 2004 called DNG (Digital Negative) format. Adobe states that DNG "... *is a new, publicly available archival format for the raw files generated by digital cameras. By addressing the lack of an open standard for the raw files created by individual camera models, DNG helps ensure that photographers will be able to access their files in the future.*"[19] It is hoping to become the de facto standard RAW format for DSCs to generate. Clearly, the main motivation for Adobe is to maintain its dominant position in the imaging software industry, trying to stop the need of adding support in its imaging applications for every new RAW format introduced with a new DSC.

However, there are still relatively few software applications, primarily Adobe products, supporting this format; as for DSC support, Hasselblad announced that they will allow data to be exported into the DNG format and Leica Camera AG plans to have native DNG format support[20], yet no major player in this market has committed to it. One reason why there are so many RAW image data format existing is

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[18] Examples are Canon's "Digital Photo Professional" and Nikon's "Nikon Capture 4" software applications.

[19] Source: Adobe Systems DNG web site: < http://www.adobe.com/products/dng/main.html>

[20] Source: Adobe Systems press release: <
http://www.adobe.com/aboutadobe/pressroom/pressreleases/200503/030805DNG.html>

because of different image sensor technology available[21]. Also, each manufacture has its own proprietary metadata taking the latest technical advancements into account. As such, it is yet to be seen whether DNG, or any other similar initiative, will prevail because of the inherent difficulty of a single format accommodating a variety of interest. Similar to the initial period of the DSC development where firms using proprietary technology to store data, the technology as well as the market need may push the DSC manufacturers to agree to a standard RAW format so that complementary products can be developed creating a positive reinforcing feedback loop.

4.2.3. Printing Trends

The increasing popularity of DSCs boosted the total number of digital pictures taken. [22] However, the 65% of pictures taken with digital cameras do not get printed. One reason is that the majority of DSC users is not aware of or did not have the necessary skills to utilize the various alternatives available to output their digital images and simply keep the images stored in the HDD of PCs, burn to a CD or leave them on the removable memory cards.

Camera and printer vendors are now heavily promoting their output solutions; conventional retailers are also pushing in an attempt to drive consumers back to their shops being equipped with digital-enabled mini-labs and kiosks. Currently, 60-70% of digital images are printed in the home[23]; printer manufacturers are striving to maintain their lead over retail shops so that they can retain their share of the photo printing market. The cost per print of using home printer have become very close to the conventional film printing at retail, which historically was in the range of $0.20-$0.25 per print.

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[21] The Bayer mosaic pattern is the most popular. Other patterns include each sensor records one color each, each sensor capture all three primary colors at once, and sensors that sense two ranges of brightness.

[22] InfoTrends Research group estimates that the US household penetration rate will reach more than 60% in 2006 from 40% in 2004.

[23] Source: PMA Marketing Research 2005.

Retailers, on the other hand, are pushing back to drive consumers back to their store, having various alternatives to print the consumer's digital photos. Options include digital mini-labs which maintain the cost per print at $0.20-$0.25, and photo kiosks being $0.10-$0.15 higher. They also utilize the Internet providing web-based upload with mail order services at $0.20-$0.30 per print, or a hybrid approach having upload services with same day pick up at the shop.

Historically, the conventional photofinishing business was divided between a few dominant players primarily Kodak and Fujifilm. Because of the transition to digital technology, the print fulfillment industry is experiencing fierce competition with the home printer manufacturers such as Canon, Epson and HP entering the market. While home printing is expected to continue being the most popular method of printing, the dominant fulfilling process is yet to be determined.

4.2.4. Removable Memory Card Trends

The storage prerequisites for digital imaging applications include devices that are compact in size, offer a high level of capacity, have limited power consumption needs, and have the ability to withstand extreme conditions. Such requirements of characteristics calls for a technology called "flash memory"— a type of nonvolatile memory where the memory pattern can be erased by very large arrays of bytes. The flash memory feature is produced in a card format, which subsequently is built in or inserted into a product.

IDC estimates that worldwide shipments of flash-based removable memory cards will rise at a compound annual growth rate (CAGR) of 32% from 2004 through 2008. IDC projects that over the same period, average selling prices will decline by over 16% annually, while average capacity (measured by megabytes per card) will increase 16% per year. The primary driver for flash-based removable memory card adoption is the DSC, though cell phones are estimated to increase its percentage. (See Figure 4-7)

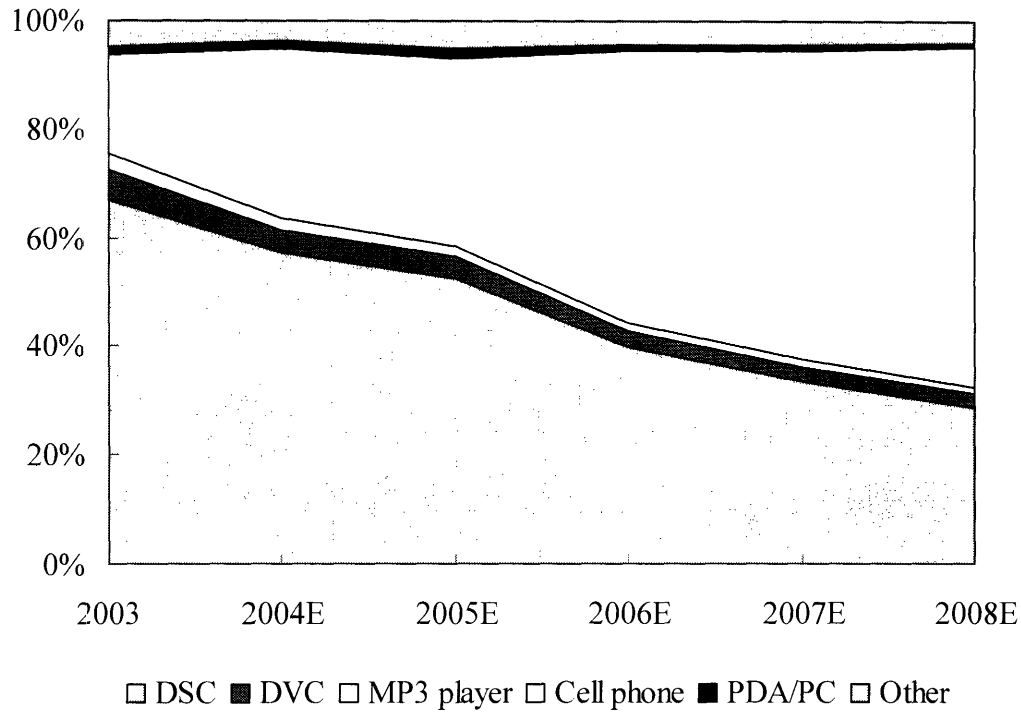

Figure 4-7: Worldwide Flash-based Removable Memory Card Shipment by Application[24]

In the context of digital imaging, removable memory cards used by DSCs are considered as an important platform technology. As of the writing of this thesis, there are four major removable memory card formats[25]: CompactFlash® (CF), Secure Digital (SD) memory card, Memory Stick, and xD-Picture Card (See Table B-1 for a comparison of each removable memory card format and Table B-2 the respective card format's promotional organizations); according to The NPD Group, in 2004 SD memory card was the market share leader having 40.7%.[26]

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[24] Source: Adapted from S&P's Industry Survey "Computers: Storage & Peripherals" which referenced IDC's data.

[25] Toshiba announced in March 10, 2005 that they will discontinue the production of Smart Media cards. Source: http://neasia.nikkeibp.com/newsarchivedetail/daily_news/000681

[26] Source: PRNewswire, "SD Card Association at CES Hosts SD Pavilion and Adds Key Manufacturers to Advance Worldwide Wireless Initiatives", Jan. 6, 2005. <http://sev.prnewswire.com/computer-electronics/20050106/NYTH10706012005-1.html>

Chapter 5: Keys for Digital Imaging Growth

5.1. Overview

Digital imaging, as a disruptive technology to conventional film-based photography, has established a new market driven by DSC sales and its complements. Many incremental innovations had occurred, most notably the image sensors that improved the quality of images produced by DSC; DSC generated images are becoming comparable to conventional photography printouts. Existing products, such as ink jet printers, also innovated and expanded its scope to become a major complement for the DSC. Even though a disruption from film to digital imaging had occurred, the value chain of photography still remains even though the major players within those respective value chains had changed. However, the digital imaging industry faces challenges in order for digital photography and its related products to sustain growth as well as provide users benefits to its full potential.

This chapter examines the transition from analog to digital photography. Based on the current trend in the digital imaging industry presented in the previous chapter, we identify challenges and analyze the impact to the dynamics of the photography value chain.

5.2. Transition from Analog to Digital Photography

5.2.1. Conventional Film Photography

Figure 5-1 shows the conventional film industry value chain identifying the primary value creating device for each phase and the medium that links the chain. The set of device and medium creates the overall user value at each phase. In other words, one would not create user value without the other, as such are considered complements.

Considering the Capture Phase, the camera and the film are the critical components that initiate the photography value chain. While the film serves as the critical component to record the 'moment', cameras serves as the complementary device that is necessary to satisfy the user's need. The SLR and compact type camera having a different set of features and flexibilities are two examples of such segmentation. Moreover, among those two types, many innovations (e.g. automatic focus, scene analysis capability) had occurred and attempts were made to create new market segments[27] for growth.

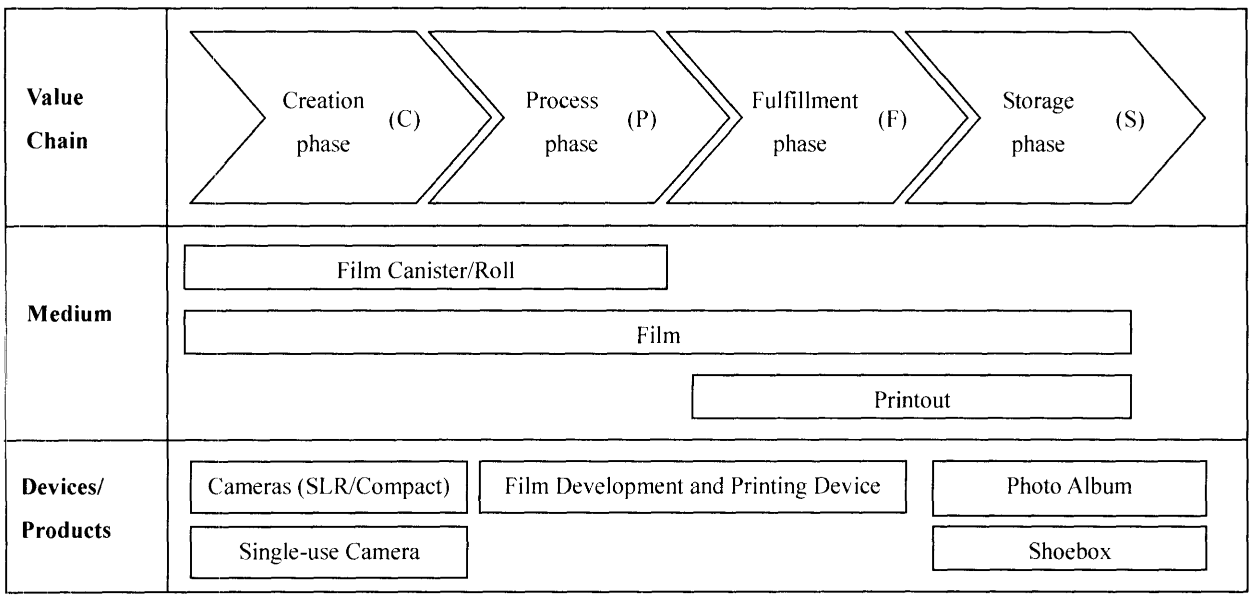

Figure 5-1: Conventional Photography Value Creator and Linking Medium[28]

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[27] For example, Canon cultivated a new market segment called "Young mother" who had interest in taking high-quality pictures but existing SLR cameras didn't appeal to them due to its design and weight.

[28] For APS (Advanced Photo System) films, the film canister is paired up with the film and bridges to the Storage phase.

The Process and Fulfillment Phase were both taken care by professional equipment; users would bring their rolls of film to a retail photo shop, have the film developed and prints made at a later time[29]. In general, all shots are printed regardless of user preferences because the user has no means to know which one he or she will like, in advance, and the price of printing had become extremely low, due to economy of scale, users accept this option to see all the results.[30] At this point, there is a transition of value and utility from film to printout (See Figure 5-2) because that is the first time the user will be able to see the captured moment. Firms that provide such a service are critical. In the conventional photography industry, film manufacturers dominated the value chain providing not only the film and paper medium but also the film development and printing process.

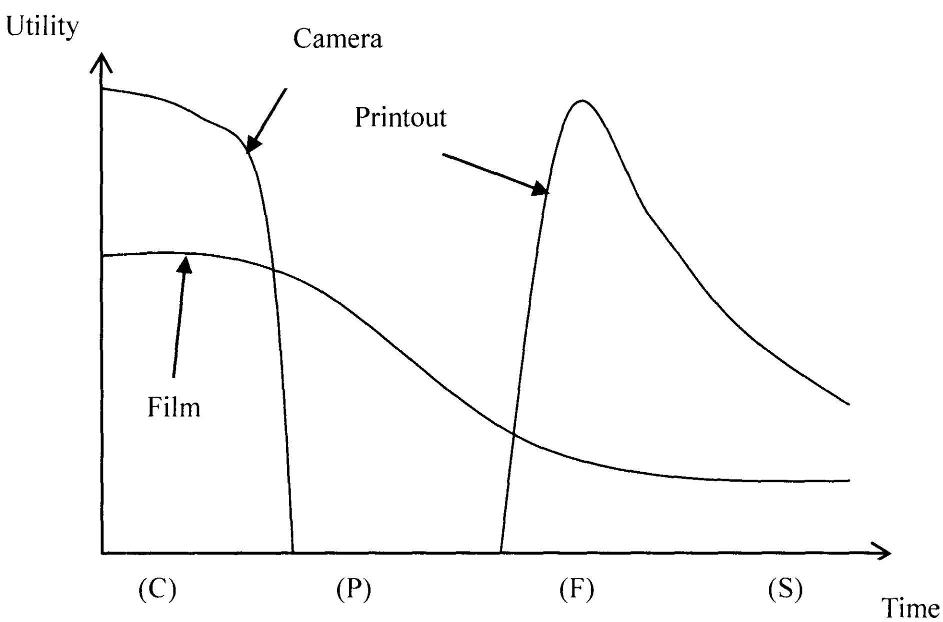

Figure 5-2: Film and Printout Utility

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[29] Currently the typical wait time is 1 hour, an indication of how advanced the process had become.

[30] It is difficult to distinguish the picture quality just from a negative film.

However, the key medium that runs through the value chain that captures most of the value is the film itself. The bottom line is that both film and printout are the key medium that bridges the value chain. Moreover, unlike cameras where the turnover cycle is relatively long, both medium are repeatedly purchased and used as consumables once they pass through the value chain. This allows film manufacturers that dominate the market enjoy the economy of scale and capture the most profit.

5.2.2. Digital Photography

Similar to the previous section, Figure 5-3 shows the digital imaging industry value chain, identifying the primary value creating device for each phase and the medium that links those chains.

In contract to the conventional film photography value chain, the both the value creator, DSC, and the medium, removable memory card, crosses over the value chain. The Capture Phase device is equipped with the Process Phase and the Fulfillment Phase[31] and therefore creates more value at the point of shoot. This instant viewing triggered the emergence of the DSC dominant design. Another interesting contrast is the physical medium: film, while an extremely important medium connecting the photography chains, films cannot bring fulfillment to the user without professional assistance even though it had passed the Process Phase. On the other hand, a removable memory card with the digital image stored can be viewed anywhere, anytime without help from others, as long as there is a device that can display the file. Because of these similarities, a removable memory card is commonly referred to as a "digital negative."

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[31] It is interesting to note that prior to the emergence of the DSC dominant design in the mid-1990's, the only difference is the DSC not covering the Fulfillment phase. In other words, the DSC was not equipped with a monitor.

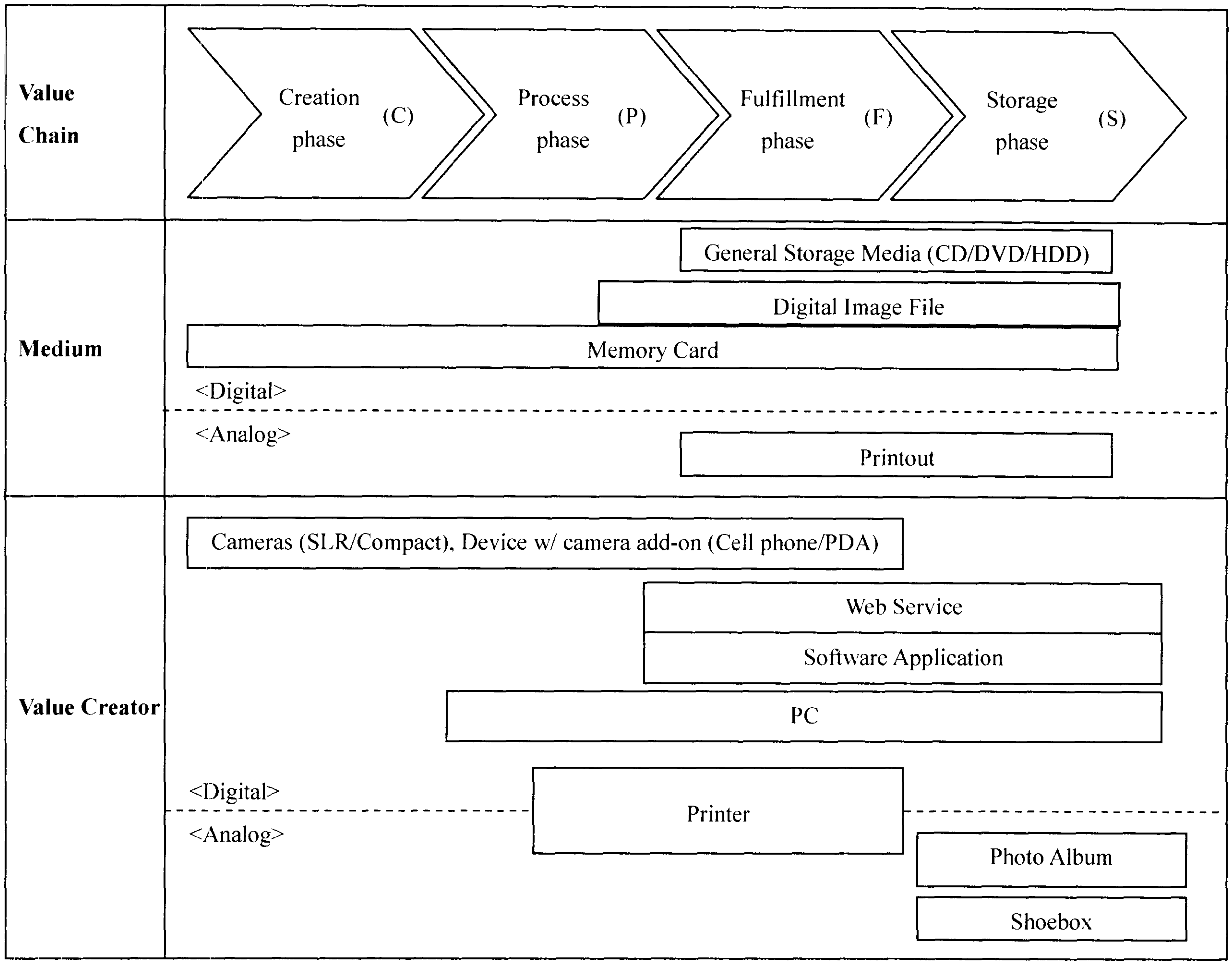

Figure 5-3: Digital Photography Value Creator and Linking Medium

Considering the Fulfillment and Storage Phase, there are many similarities between the two value chains: the physical printout, photo album or shoebox storage. However, digital imaging has a much broader set of application as well as pool of services that are possible because of the data being digital. First, the Fulfillment Phase can be managed by the consumer him/herself using a PC and color printer. The flexibility of print size as well as image editing such as cropping, color correction and image enhancement are enabled because of the existence of image editing software which increases the utility of the image. (See Figure 5-4) The caveat, however, is that there is some technical skills required even though software vendors are innovating to make such process very easy. Second, taking advantage of the Internet, photo sharing is becoming very easy either sending images via email or posting on an online photo album. And lastly, there are many external storage media that can help keeping the digital data organized and secure; as shown in Figure 5-4, the relative utility of the removable memory card will be lower at the later phase as it will be reused for the Capture Phase once it unloads the data it has stored. The primary reason for such a broad application is due to the utilization of the JPEG compression technology that was widely accessible without any additional effort for the user.

Finally, it is important to note that there are no dominant firms controlling the digital imaging value chain. On one hand, the proliferation of digital images spurred independent innovation in each phase, enhancing the total experience of digital imaging in a positive way. On the other hand, because of the magnitude of change in the process, requirement of new skills and knowledge of handling digital data, and the fragmentation of product and services, there are still consumers reluctant to enjoy the full benefit of digital imaging.

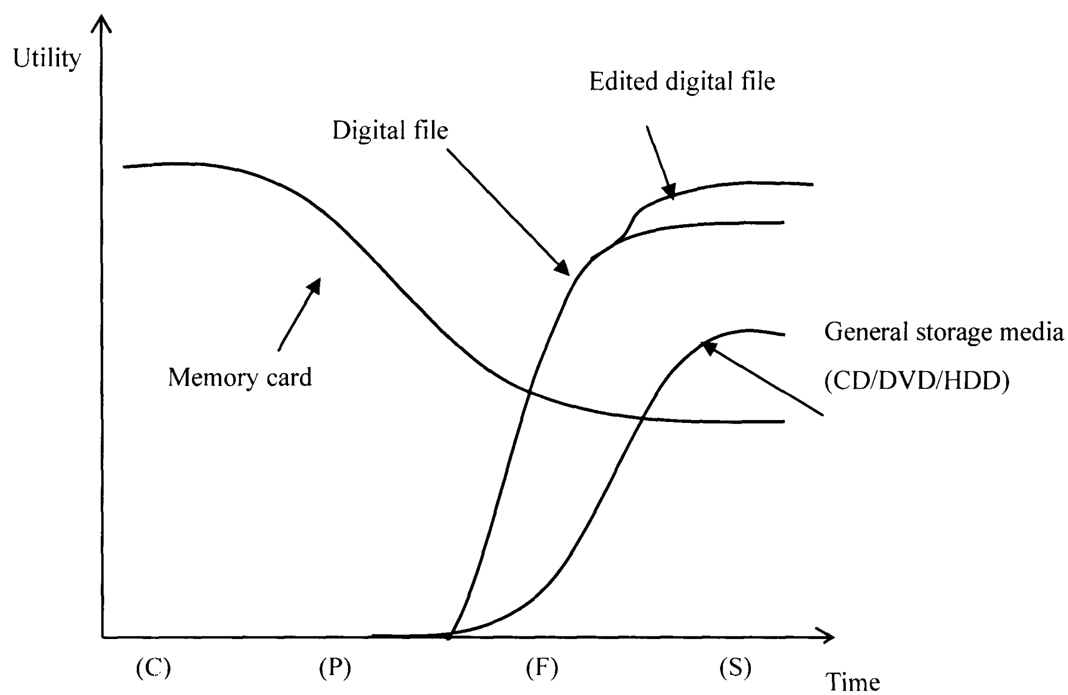

Figure 5-4: Digital File and Storage Media Utility

5.2.3. Summary of Product Transition from Conventional Photography to Digital Imaging

Table 5-1 presents a summary of product or service transition from conventional photography to digital imaging. While new devices and services emerged, each one of them have leveraged existing resources which lowered the barrier to entry and accelerated the introduction of new products meeting the time to market.

Table 5-1: Technology Transition from Conventional to Digital Photography

Product/ Service[32]	**Core Technology**	**Utilization/Leverage**	**Driving force for adoption**	**Challenge**
DSC (C)	Image sensor, lens, image processor	Film camera, flash-based memory card, USB, image compression, color	Instant viewing,	Data file storage/ management, device reaction speed
Print shop (F)	Print technology, paper	Film-based shops	High-quality print out	Not yet an habit, transfer of data
Cell phone (C)	Size of camera module	Cell phone network	Casual capture	Image quality
Inkjet printer (F)	Printer head, ink, paper	PC, Color printer	Photo quality	Perceived cost, maintenance
Imaging software (P/F/S)	Image editing, ease of use	PC, Imaging SDK, JPEG codec[33]	Convenience, ease of use	Image editing
Photo Web service (P/F/S)	User interface, broad sharing,	Internet, Web browser, JPEG codec	Convenience	Awareness, delivery, connection speed

[32] The letter in parenthesis corresponds to the photography value chain symbol.

[33] A free C programming language JPEG library developed by a group called the Independent JPEG Group contributed immensely to the adoption of the JPEG technology for PC and Web applications. <http://www.ijg.org/>

5.3. Challenges in the Digital Imaging Value Chain

Although the digital imaging industry had experienced phenomenal growth, various challenges associated with each value chain still remains in order to further sustain its growth.

Capture Phase Challenges

For the Capture Phase, the sustainability of DSC sales is the primary focus as the market becomes saturated. While DSC manufacturers are continuing innovations to enhance existing features, they are also improving the internal process for DSC manufacturing and incremental development. One key aspect of the product feature where innovations are occurring relates to image quality; not only capturing the scene, which is essentially the same as film photography, but also storing necessary information for high-quality reproduction at the Fulfillment Phase, primarily by a printer[34]. Passing on such data through the imaging value chain without being discarded is becoming a great challenge.

Fulfillment Phase Challenges

For the Fulfillment Phase, 'no-hassle printing' is the key as there is a steady need for consumers to have their favorite picture printed.[35] A major initiative led by the DSC and home printer manufactures is allowing consumers "direct printing" either by printers accepting memory cards or directly connecting the DSC with the printer without a PC involved.

As for the challenge for the former case, because multiple incompatible removable memory card formats are used in various DCSs, the printers, home printers as well as digital photo kiosks, are forced to make a design decision: either provide multiple memory card slots for each removable card type (See Figure 5-5),

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[34] The benchmark for digital imaging is film quality.

[35] This is a big transition from conventional photography, where all pictures had to be printed at least once, whereas in digital imaging, viewing (or previewing) is done on the monitor and pictures are 'selectively' printed, reducing the total number of prints but increasing the need for high-quality printouts.

or choose one type to support and have the consumer use an adapter that will allow the card to be read. From a printer manufacture's perspective, the former approach means additional cost as well as product design inflexibility.

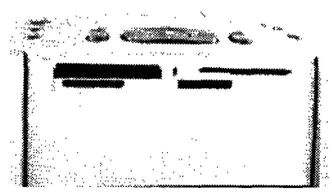

Figure 5-5: A Printer with Multiple Removable Memory Card Slots

Addressing the DSC-printer connectivity issue, camera and printer manufacturers collaborated to create a new standard protocol that enables direct printing. This new standard is called PictBridge released on February 2003 by CIPA.[36] An important point to note is that, similar to Exif, PictBridge is utilizing existing standardized technologies as its foundation, namely PTP (Picture Transfer Protocol)[37] and XML (Extensible Markup Language).

Storage Phase Challenges

There are primarily two challenges for the Storage Phase. One relates to the actual storage media, and the other is accessibility of those externally stored data.

First, as in any external storage media, there is no guarantee for that media to be readable in the future. 8 mm films and cassette tapes are examples where the media itself became replaced by newer media

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[36] Developed by Canon Inc., Fuji Photo Film Co., Ltd., Hewlett-Packard Co., Olympus Optical Co., Ltd., Seiko Epson Corp., and Sony Corp. As of March 28, 2005, there are nearly 800 conforming products including DSCs, digital camcorders, camera phones, and printers.

[37] Formally an US national standard PIMA 15740:2000, later adopted as an international standard by ISO as ISO 15740:2005.

formats, DVC tapes and CDs respectively. Even though the data conversion may be easier compared to the previous examples because of the data being digital, an additional challenge is whether there will be software and/or hardware that would be able to read and decode those data stored in those media formats.

The accessibility challenge includes indexing, searching and ubiquitous viewing. Image file generated in a DSC records data according to the Design rule for Camera File system (DCF) standard developed by JEITA. The DCF standard stipulates the structure and naming conventions of both the directory and a profile of the image file format. (See example in Appendix A.1) Because of its simplicity, it is easy to implement but on the other hand, it is difficult to organize and search the image data as is. Because of this issue, new efforts are emerging to find a long term solution.[38]

5.4. Battles of Digital Imaging Platform Technologies

In this subsection, we analyze two platform technologies, specifically image data format and removable memory card format, which has implications to the sustaining growth of digital imaging but have not been fully addressed at this time.

We use Suarez's framework outlined in Chapter 2 to analyze the factors and strategic implications for a new format to be introduced and its diffusion strategies. Given the challenges previously presented, we hypothesize the following technology battle scenarios:

Scenario 1: *Replacement of JPEG Compression* — battle against existing standard)

Scenario 2: *Convergence of Removable Memory Card Format* — battle of existing set of technologies

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[38] The PASS (Picture Archiving and Sharing Standard) initiative is such an example. See <http://konicaminolta.com/releases/2005/0221_01_01.html>

5.4.1. Scenario 1: Replacement of JPEG Compression

This is a technology battle against an established and widely deployed standard. In this analysis, we assume that the alternative compression technology is already an International Standard. In other words, the first two milestones, Phase I (R&D Build Up) and Phase II (Technical Feasibility), have passed. We examine this scenario both from the firm as well as environment-level factors.

Firm-level Factor Analysis

In general, in order for firms to adopt a new technology that replaces an existing one, its technical superiority must be significant particularly in the area where the customers care about most. In the context of digital imaging, the compression performance for the high image quality (or low compression ratio) is critical. Also, technical compatibility with JPEG technology can also play an important role during the transition and migration period. Without backward compatibility, it would be very difficult to change the digital imaging industry as no single firm control the whole value chain.

Complimentary assets beyond the digital imaging industry must be available creating reinforcing forces to increase product attractiveness. In this particular case, the credibility of the alternate technology must be substantial otherwise there is very little incentive for complementors to support it. At the early stage of technology introduction, however, if there is a large installed base, even in a niche market, that can be the basis of a positive reinforcing force that increases the attractiveness of specific technology should that niche application becomes a mainstream product.

For a firm to adopt a new technology, the entry timing must be after Phase II which proves the technical feasibility. The product pricing, however, would have a direct impact: new components may not have reached marginal cost and additional R&D investment is required to incorporate into the existing architecture. This issue may be reduced if the introduction was gradual having very few models such as high-end products that can afford the additional cost implementing the new technology. This point also ties with the previous point made by introducing a product in a niche market.

Considering the intellectual property (IP) issues, the licensing policy of the new compression technology must be addressed well in advance. Due to the nature of the technology domain, many patents exist that covers various aspects of a compression algorithm and it is very unlikely that a single firm owns the whole compression process. As such, the most dangerous situation is when the IP owner is unknown or unwilling to license their portion of the technology at a reasonable price. Furthermore, unlike the music or movie industry, the photography industry has not had a substantial third party that will create commercial content. For example, the distribution of DVD movies played a critical role in the diffusion and replacement of VHS movies. Given that there are limited revenue streams for digital imaging, the implied assumption for users as well as manufacturers is that the compression technology must be free of licensing fees. However, the fact that the technology is being offered free may be a requirement but does not necessarily mean it is sufficient to be widely adopted.[39] Since the compression technology itself is not necessarily the primary concern of the end users, the focus for firms with regards to marketing and PR efforts, it should continue being the product and benefits that are based on the new technology.

Environment-level Factor Analysis

Adoption by an industry organization as a standard, such as Exif, will help the battle. However, in order for major DSC manufacturers to agree on a standard, aforementioned firm-level factors as well as other environmental factors must be addressed, which may take a long time.

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[39] The classical example is the PNG image format, which was developed as an alternative to GIF since the patent owner required licensing fees. Even though PNG was offered free, many software companies continued using GIF paying the license fee.

Creating a network effect without a market leader becomes a chicken-and-egg problem. In the digital imaging industry, because the DCS manufacturers benefited from the existing JPEG installed base, initial support by PC operating systems and software applications may be a requirement for adoption as the DCS will lose one of its important viewing options. On the other hand, unless there is sufficient need for the operating system or application to support such a new format and compression scheme, there is less incentive for software vendors to support the new technology. CE devices may be able to generate such a need; however the switching cost is very high for hardware manufacturers given the wide adoption of JPEG technology. Moreover, if there is any kind of uncertainty in IP, primarily patents, it will hinder the adoption of a new technology. The DCS industry has had been collaborative in some aspects, e.g. file format, and at the same time heavily competing with each other. Should there be a strong justification to adopt the new technology, given that all other factors are properly addressed, the industry as a whole may take the lead in driving adoption.

5.4.2. Scenario 2: Convergence of Removable Memory Card Format

This is a technology battle against existing technologies in the market. Considering the current stage, this battle is conducted in Phase IV (Decisive Battle). Again, we examine this situation both from the firm as well as environment-level factors.

Firm-level Factor Analysis

The flash memory technology selection process involves evaluating a list of criteria related to system performance (memory density, speed, switch-on-time, and total system power consumption) as well as total memory system cost. In the context of memory cards, the form factor (i.e. physical size and shape) is also considered critical. The current market leader is CF cards as it has the most capacity. However, SD memory cards are gaining momentum due to its small form factor and increase in capacity.

Additional features such as security or access control may be considered a differentiator. However, there are no compelling need for such functionality for the digital imaging industry at this time.

While the dominant user of flash memory cards is DCSs, cell phones are expected to grow rapidly. (See Figure 4-7) Also, given the popularization of DSCs and digital imaging, we can expect an increase in the rate of products that can take advantage of this growing market, e.g. DVD players and printers, to be equipped with a memory card slot. And in fact, organizations that are promoting the memory card format have such a vision where their card is used ubiquitously. (See Appendix C) Considering this factor, the SD card and Memory Stick seems to be in the forefront as each card format is backed up by major CE firms, Matsushita and Sony, respectively. This also relates to the product portfolio of the firm which can increase the installed base as well.

Instead of memory card proponents maneuvering on its own, each memory card has formed an independent organization that deals with licensing, specification revision and supporting company relationship building. (See Table B-2) Transferring the control over to an outside organization does have its inherent risk as opposed to keeping it proprietary. However, the openness increases the attractiveness of the technology hence increase the supporting community. The more installed base, the more benefit to firms; due to economy of scale, the relative price per storage capacity can decrease. Memory card manufacturers generally do not conduct marketing or PR campaigns directly to the end users. Instead, the awareness level is indirectly influenced by the installed base.

Environment-level Factor Analysis

While regulations and certification requirements do exist, there are no particular regulations in terms of standard known as to the memory card selection for a class of products. For example, the Japanese DSC industry organization neither endorses nor precludes any memory card format; it is the individual firm's decision. That said, clearly there is a network externality; the more people and products using the same memory card format, the utility will increase. However, unlike the case with video tape format battle (See Cusumano, et al., 1992), memory cards can be compatible using an adapter, therefore reducing the power of externalities. The switching cost is high, both for the manufacture as they need to reinvest in a new format, and for the user as memory card are not yet commodities. Memory card technology is also heavily protected by patents; no single firm owns the whole technology. Unlike image compression technology, however, manufacturers respect the intellectual property and are comfortable paying license fees, as long as they are reasonable. The memory card part of the digital imaging industry today is structured in a way that the memory card as well as device manufacturers are complementing each other. For example, with the DCS industry, high-resolution camera requires larger memory capacity; DSC sale creates demand for memory cards. This reinforcing cycle is similar to the relationship between a PC and HDD.

On one hand, there seems to be very little incentives for manufactures that generate data, e.g. DSC, to converge to a single format. On the other hand products that accept those cards, e.g. printers, do have a strong reason for it to be uniform. While there is a possibility of convergence, unless the market power of DSCs is overturned, it is very difficult for the industry to agree on a single format.

Chapter 6: Conclusion

This thesis presents a case study on means to expand the application of digital imaging by analyzing the current trend, the associated challenges, and examining two key technologies, the image file data format and removable memory card, as the key to digital imaging's growth. The key questions this thesis attempts to address were as follows:

- What are the success factors for digital imaging to date? What can be inhibiting its growth?
- What are challenges that the digital imaging industry face? In what way should the industry players respond in order to sustain the growth and utilization of digital imaging?
- What are the lessons to be learned from the conventional film photography industry that are applicable to the digital imaging industry?
- If there are solutions to the problems the digital imaging industry face, what are the strategic alternatives to realize such a solution?

This study has shown valuable insights to the above questions. The emergence of a dominant design for a DSC triggered the wide deployment of digital-based photography and its rapid pace of innovation of its key components (e.g. image sensors, image processors, etc.). New entrants, particularly the CE firms, contributed to accelerate the rate of which such innovation had occurred bringing their expertise and resources to attract new consumers beyond a conventional photographer. The standardization of an image file format driven by the DSC manufacturers at an early stage, and the adoption of the widely deployed JPEG compression technology, played an important role in the initial proliferation of digital imaging. Unlike conventional film photography where the film manufacturers not only provided the key media that bridge the value chain but also dominated the conversion from film to paper, in the current digital imaging industry, no single firm has dominant control over the key media that runs through the whole value chain for digital imaging – the digital image data format.

While digital imaging is disrupting the conventional film photography industry much rapidly than anticipated by the film manufacturers, the photography value chain still remains valid: the key players that creates value within the chain has changed forcing incumbent firms to revise their business model and seek for alternate revenue streams by repositioning itself within the value chain. And, throughout the value chain, the image quality level of conventional film photography remains as the benchmark for digital imaging which drives the DSC innovation trajectory as well as complementary products such as printers. Because the picture is in a digital form, new means of data sharing, i.e. email and web albums, has become more popular and contributing to the growth of digital imaging. However, the increase in file size may become a bottleneck that balances the growth trajectory.

Part of the success of film photography was due to having a standard for the media format (35mm film) and media storage (film canister) which allowed complementary products throughout the photography value chain to increase the attractiveness and convenience of film photography. Digital imaging, on the other hand, only has a standard for the media format (JPEG compressed images). Should the media storage format, the removable memory card format, converge to a standard form the potential benefits are quite clear from the users' perspective as well as devices down the photography value chain. However, due to high switching cost for manufacturers and easy replacement of removable memory card format using adaptors for consumers, there is low incentive for DSC manufacturers to converge to a single format.

The standard compression scheme, JPEG, used as the image data format for DSC, and digital imaging in general, may not be as effective as it used to be, due to the increase in data size as image sensor resolution and image quality requirements becomes higher. Though, because it is the de facto standard platform technology for digital imaging, changing the compression scheme has enormous implications affecting all players in the photography value chain. As such, simply replacing such a platform technology with a new one is much more difficult unless there is a significant performance enhancement that justifies such a change, a commitment and support throughout the photography value chain, or a new network effect driven by third party vendors providing content using the new technology that will increase the attractiveness. If there is a new technology disruption, JPEG may be replaced, though such an indication is not visible in the horizon at this time.

After a period of exponential growth, digital imaging is gradually shifting into the maturity phase of the industry life cycle. In order for the industry as a whole to enter a sustainable growth trajectory, further convergence on technology standards may be necessary. This may be driven by the DSC industry, as it did with the Exif standard, or by competition in the market. Either way, new standards has a potential to create new opportunities attracting even more complementors, hence creating a positive reinforcing force to increase the value of the digital imaging industry.

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Appendix A : Overview of DSC Format Technologies

A.1. DCF Directory Structure Example

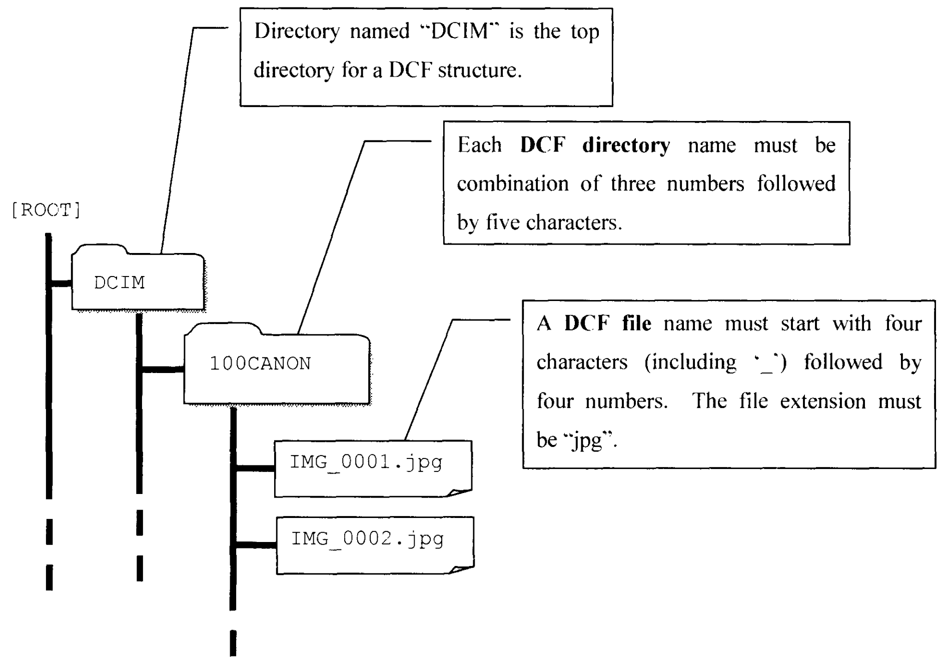

Figure A-1: Example DCF Directory and DCF Data File Structure

A.2. Exif Standard

The Exif is a standard which defines the image file format generated in a DSC and used by related systems that handles images that are created by DSCs. The specification defines the structure of the image format, including a data compression scheme, and the set of tags to store the metadata of the recorded image. For the image data, JPEG is used for compressed images (See Figure A-2) and TIFF[40] is used for uncompressed images (See Figure A-3). A set of metadata is recorded using the TIFF structure and covers information such as basic image parameters (e.g. image width and height, and colorspace) and camera setting (e.g. shutter speed and F-number).

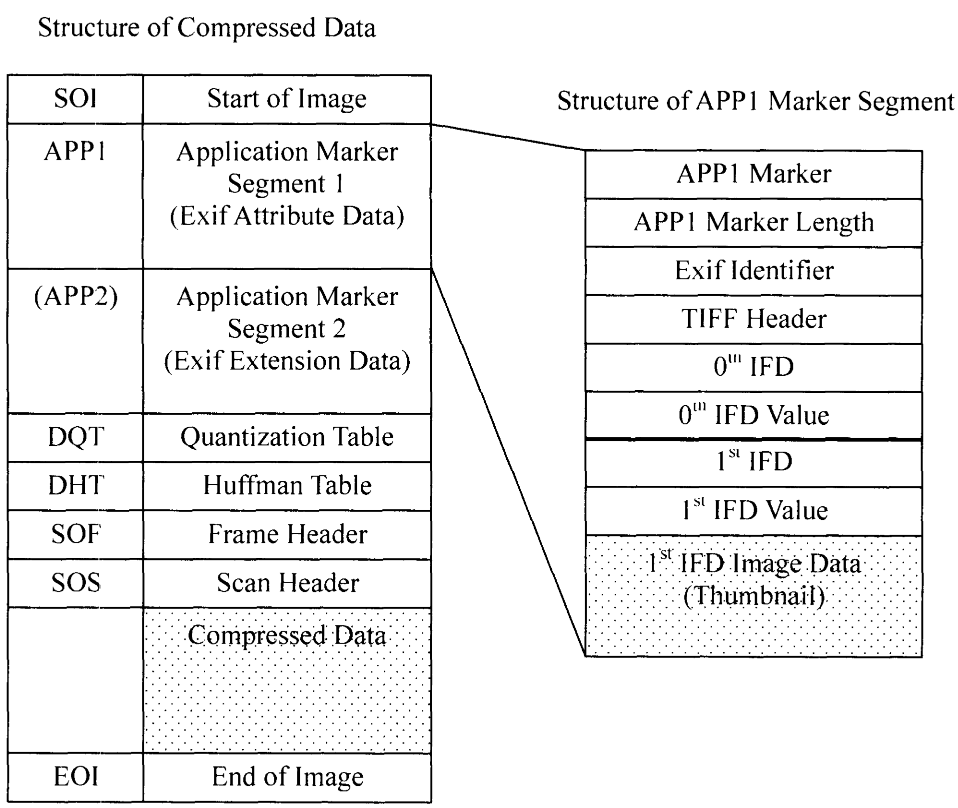

Figure A-2: Structure of Exif Image File (JPEG Compressed)

[40] Adobe Systems, "TIFF Revision 6.0", June 3, 1992

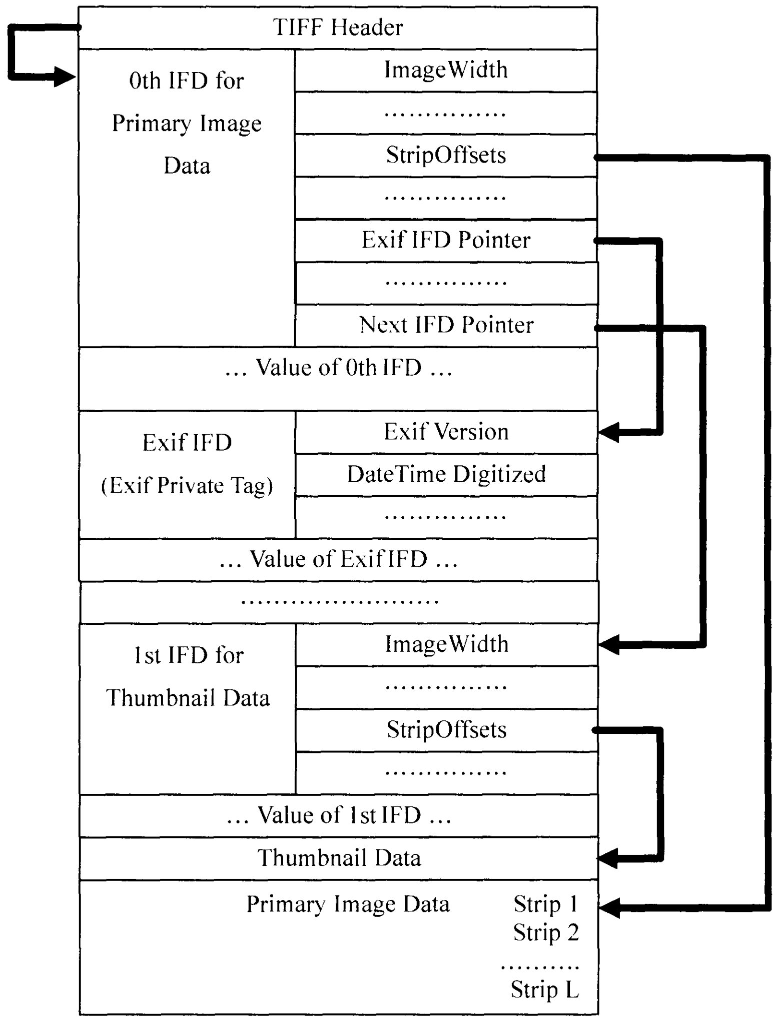

Figure A-3: Structure of Exif Image File (Uncompressed)

A.3. JPEG Standard

The JPEG encoder process consists of dividing each color component of the source image into 8x8 blocks, perform two-dimensional DCT on each block, quantizing each DCT coefficient uniformly, subtracting the quantized DC coefficient from the corresponding term in the previous block, and then entropy code the quantized coefficients using variable length codes (VLCs). The JPEG decoder process is performed by inverting each of the encoder operations in the reverse order. The overall encoding and decoding process is shown in Figure A-4.

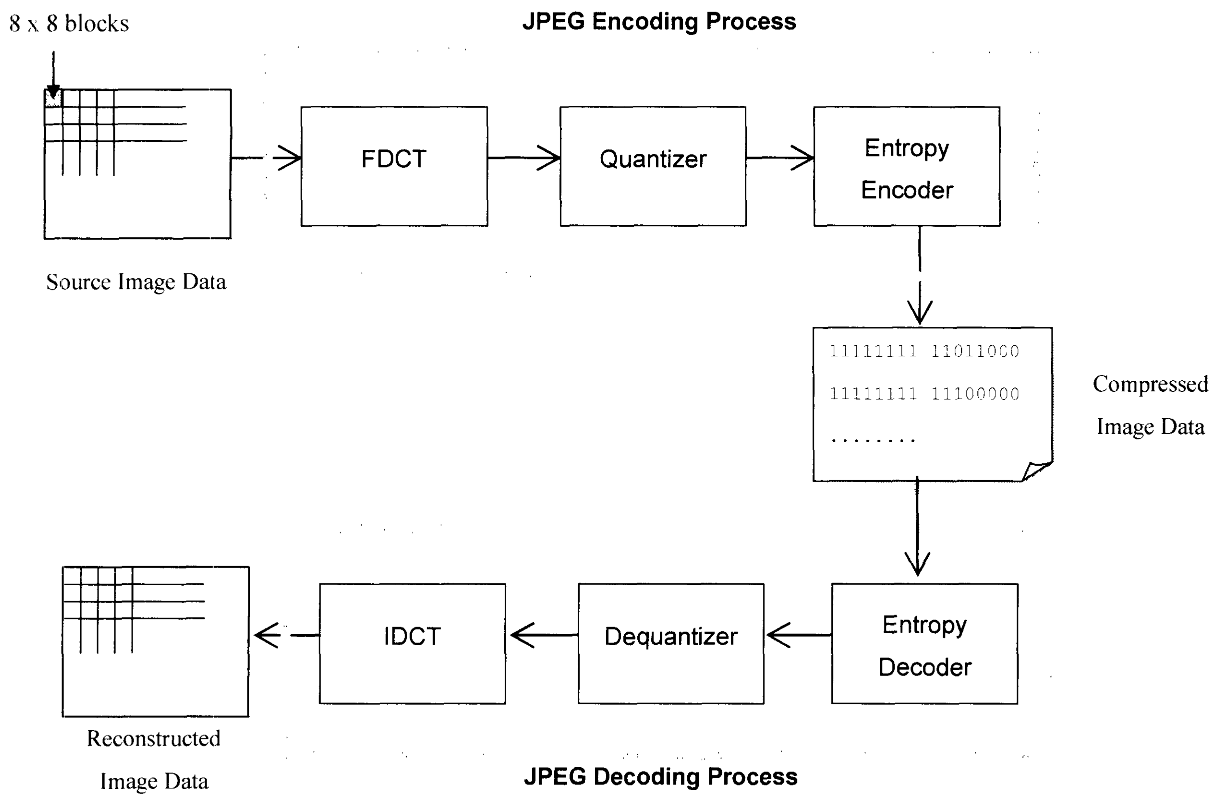

Figure A-4: Overview of the JPEG Compression and Decompression Process

For a short technical introduction to the JPEG algorithms see Wallace (1991), and for a more complete description, see Pennebaker and Mitchell (1993).

Appendix B : DSC Removable Memory Card Comparison

Table B-1: DSC Removable Memory Card Specification Comparison[41]

Format	Maximum Capacity	Physical Size (mm)/ Weight (g)	Description
CompactFlash®	16MB-1GB (Type I), 1GB -8GB (Type II)	43x36x3.3 (Type I) 43x36x5 (Type II)/ 8-15	• Format introduced by SanDisk in 1994 • Licensed for free to other firms through the CompactFlash Association • Wide selection of capacity points • No security feature
Secure Digital™	32MB-1GB	32x24x2.1/ 2	• Co-developed by SanDisk, Matsushita and Toshiba with additional IP from Intel and IBM • Open standard, but not free; manufacturers must pay licensing fees to developers though the SD Association • Compatible with MMC • Secure format (SDMI compliant)
Memory Stick™	32MB-256MB/ 256MB-2GB (PRO)	21.5x50x2.8/ 4	• Proprietary format introduced by Sony in 1998 • Universal link across several Sony and Sony-licensed products • Secure "MagicGate" version of MS available • Smaller MS Duo for smaller devices (1/2 sized) • MS PRO a high capacity and high-speed data transfer version co-developed with SanDisk and Sony (released in April, 2005)
xD-Picture Card™	64MB-1GB	20x25x1.7/ 2	• Co-developed by Olympus and Fujifilm; manufacturing done by Toshiba. • A successor of SmartMedia card[42] • Exclusive use for digital cameras

[41] Source: Adapted from Xavier Pucel, "Worldwide Flash Memory Card Market Forecast and Analysis, 1999-2004", IDC 23117, October, 2000, with updated data relevant to DCS. (As of April 1, 2005)

[42] It is reported that Toshiba is considering discontinuing the production of SmartMedia cards. Source: Nikkei Electronics, March 8, 2005

Table B-2: Removable Memory Card Promotion Organizations

Organization Name	Membership[43]	Mission, Goal and Objective[44]	DSC Adoption
CompactFlash Association <www.compactflash.org>	2 levels: Executive/ Affiliate; 283 members; 15 executive members	To promote the world wide adoption of the CompactFlash Standard. Drive alternate source availability. Drive acceptance of CompactFlash as an industry standard across multiple platforms and markets internationally. Ensure compatibility for users of CompactFlash products. Evolve the CompactFlash standard over time while ensuring backward compatibility	Canon, Casio, Eastman Kodak, FujiFilm, Hewlett-Packard, Konica Minolta, Nikon, Sanyo
SD Card Association <www.sdcard.org>	2 levels: Executive and General; 730 members; 17 board member companies	The association aims to establish the technical and specification standards for SD Memory Card applications, to continuously promote the SD memory card as the de-facto industry standard, and to encourage the development of digital A/V, wireless communication, and digital networking products that utilize the many unique benefits of SD technology.	Canon, Casio, Eastman Kodak, Konica Minolta, Panasonic, Pentax
Sony <memorystick.com>	608 supporting companies	'memorystick.com' was designed to introduce the exciting world of Memory Stick. Since its introduction, Memory Stick has evolved from a recording media to a network media that connects products, content and people. It allows you to build your own personal network for easy transferring, storage and sharing of content and data. With its unique features, Memory Stick has	Sony, Konica Minolta

[43] As of May 1, 2005

[44] Adapted from its respective Web site.

		revolutionized the way we live, work and play -- creating a new lifestyle that's both exciting and fun!	
xD-Picture Card Office < www.xd-picture.com >	N/A; 52 licensors	N/A	FujiFilm, Olympus

Appendix C : Removable Memory Card Vision and Concepts

Each removable memory card has setup its own membership-based organization promoting its memory card format's vision of the future in order to attract more members; the goal being to increase its memory card based network or ecosystem. This appendix presents those concepts available on the respective removable memory card facilities.

<u>**SD Memory card**</u>

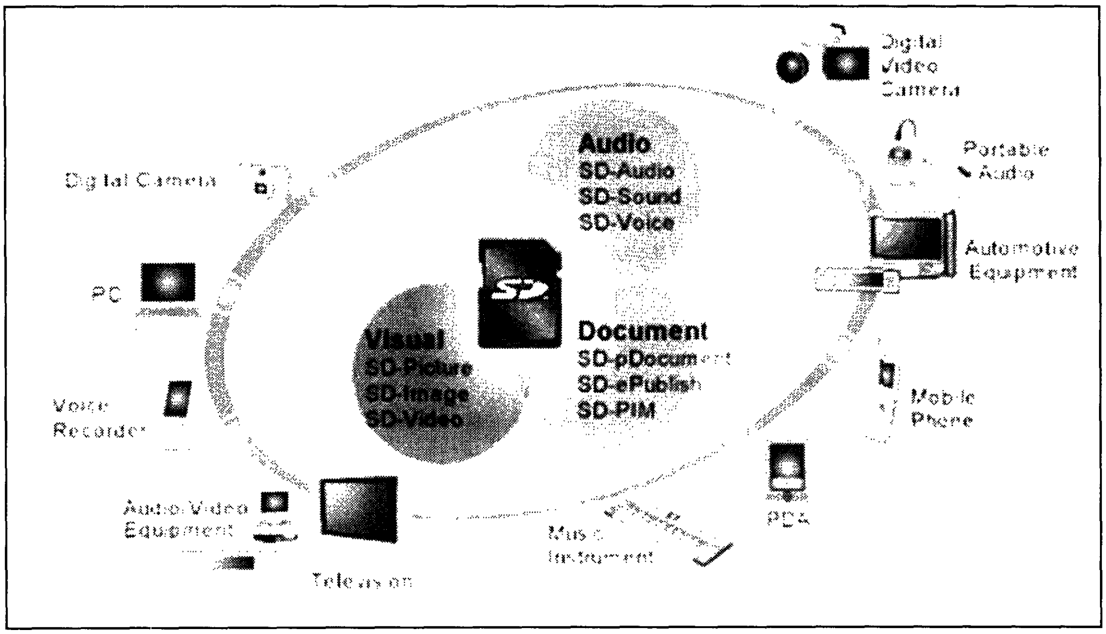

Figure C-1: SD Memory Card's Overall Concept[45]

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[45] Source: SD Card Association. <http://www.sdcard.org/>

Memory Stick

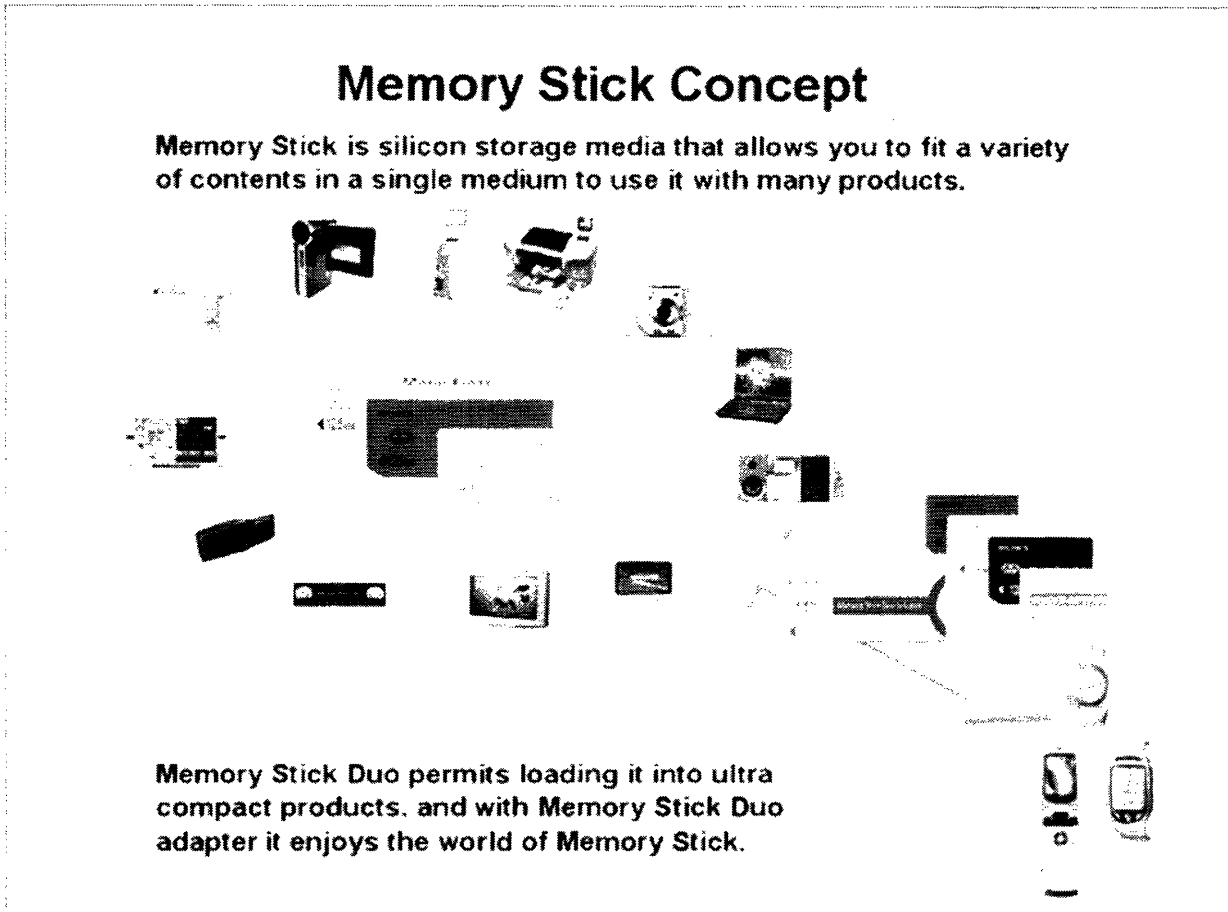

Figure C-2: Memory Stick Concept[46]

[46] Source: Memory Stick developer site < http://www.memorystick.org/>

xD-Picture Card

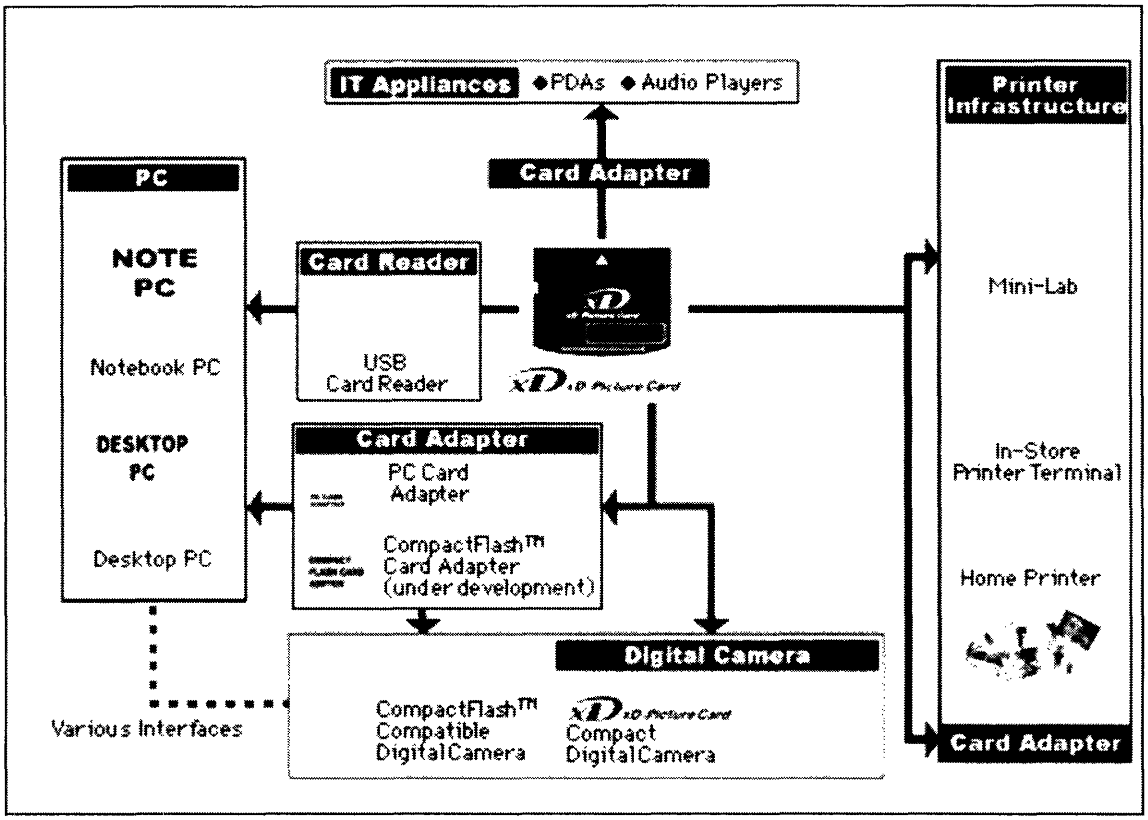

Figure C-3: xD-Picture Card Solution[47]

[47] Source: Olympus press release. < http://www.olympus.co.jp/en/news/2002b/nr020730xdpce.cfm>