年報　科学・技術・社会
第18巻(2009)，93-118頁
Japan Journal for Science, Technology & Society
VOL. 18 (2009), pp. 93-118

Failure & Technology *

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Abstract

Failure is an integral and normal part of a technology's evolution. Widely viewed, failure extends from the commercial collapse of a firm promoting a new technology and the inability of a technology to profit in the marketplace to less obvious shortcomings like suboptimal performance, poor economics, and late delivery. Historians have not paid sufficient attention to this important subject, focusing on success. The understandable tendency to focus on what worked instead on what did not has resulted in a simplified appreciation of the tortuous, demanding, and uncertain path that technologies follow to move from an idea to a reality.

This paper explores the importance of failure in the history of technology and offers a theoretical framework to approach failure. There are three basic types of failure: the failure of a new technology, the failure of an existing technology in a new environment, and the failure of an old technology against a new technology. Failures of new technologies are the most common. To succeed, a new technology must overcome five basic challenges: technological, material, competitive, operational, and environmental. Will the technology work? Do its promoters have sufficient resources to develop the technology so it is ready for use? How does it compare with its competitors? Will users actually want to use it? What happens if the environment (defined broadly to encompass the economic, political and social as well as the

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* Keywords: technology failure, business failure, fax machine, innovation, risk
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physical) changes? Several examples from the history of fax machine in the 19th and 20th century demonstrate each type of challenge.

Two areas of future research deserving special attention are how firms and organizations have developed strategies to reduce failure and how some organizations have institutionalized the partial failure of projects that consume significantly more time and resources than promised. Internal project reviews and high technology military projects are respective examples.

1. Introduction

When Federal Express launched its ZapMail fax service in 1984, the project's managers did not ask the firm's directors for permission to lose $150 million, only to be criticized for thinking too small and then ordered to lose $300 million. Yet when Federal Express discontinued ZapMail in 1986, one of the world's most technologically astute firms had indeed lost $300 million.[1]

The failure of Federal Express' new product was unusual only in its high cost. Failure is a surprisingly normal experience for technologies and firms.[2] Failure is important not only because it is so common, but also because it is unexpected. Investors expect to make money, not lose it. Inventors, executives, engineers, entrepreneurs and other proponents expect their new technology will advance their prospects, not hurt them. Yet for every Spindletop or Drake's Folly where a determined driller defied conventional wisdom to bore just a few more feet and strike oil, for every Tom Slick who successfully staked his fortune on finding oil, there were hundreds of dry wells, bankrupt firms and lost men.[3] Rarely were their stories told. Other industries have similar histories.[4]

History tends to be written about the successful, not the failed.[5] Often what writing there is about failure, especially biographies, focuses on how entrepreneurs overcame obstacles — whether technical, economic, social, or political — to succeed. A strong Whiggish whiff of human perseverance or economic or technological determinism usually can be detected. The roads not taken or only partially traveled rarely are explored in depth.[6] Failure is not a well developed issue; to quote Blaise Cronin and Elisabeth Davenport in another context, the history of failure is "undertheorized,"[7] with economists studying the subject more analytically than historians.[8] Studies by social scientists have contributed much to understanding of contemporary engineering failure.[9] Business historians tend to focus on direct competition and larger economic issues, often at the expense of the technology.[10] Historians of technology tend to concentrate on engineering design and physical failure, especially visible disasters that attract public attention, at times neglecting economic factors.[11] Management research tends to comprise comparatively recent and ahistorical case histories with the goal of improving future R&D and corporate efforts.[12] Marketing studies tend to concentrate on broad themes usually evident only in retrospect.[13] Marketing books for at a wider audience offer more enjoyable stories, but the analyses are aimed at pragmatic users, not historians.[14] The subject does retain some larger public interest, as demonstrated by the survival of *Failure* magazine, first published in 1999.

This paper will explore the importance of failure in the history of technology and offer a basic theoretical framework and *vade mecum.* A secondary goal is to provide contemporary R&D efforts with a historical understanding of the challenges they face. After describing types of failure, this paper will analyze the major challenges facing new technologies, using examples from the history of the fax machine to demonstrate each type of challenge. A discussion of how firms and organizations have developed strategies to reduce failure and the institutionalization of partial failure concludes the paper.

2. What is Failure?

Studying failure raises several theoretical and practical challenges. Perhaps the biggest question is deciding what is meant by failure. About some outcomes, there is no doubt. The commercial collapse of a firm developing or providing a new technology is an obvious failure. So too is the inability of a new technology to perform as promised. Other outcomes are less clear. If a technology finally reaches its customers several years later and significantly more expensive than promised, is that a partial failure? What about the technology that finds a much smaller market or produces a lower profit than its advocates expected? If a firm decides not to develop or license a technology that later becomes very important, is that a failure?

Failure may seem too harsh a word; the concepts of poor design or error developed by Donald Norman may be more appropriate at times.[15] Regardless of the word, the underlying questions are the same: How can we understand what individuals did or did not do at a specific time? Why did they think certain lines of development would succeed as opposed to other options? What caused a promising product to fail? Should failure be defined by the diffusion of a technology or the success of the individuals and firm promoting it? Failures of new technologies may be tightly linked to the originating firm. If the technology fails, the firm may too. Similarly, if the firm fails, the technology may disappear. Firms may disappear but the development and deployment of the technology itself continue, reflecting the spread of ideas, patents, and people despite the initial failure of a technology.

Failures in the early stages of a new technology often illustrates the large number of possible paths of development that investigators find promising. An astounding range of experimentation and development of new products often occur in an exciting and confused environment of promising leads, dead ends, and cross-fertilization of ideas, partnerships, patents, and promotion. Especially in its early years when barriers to entry are low, a new technology may spawn many different versions. Over sixty versions of an electric telegraph, for example, appeared by 1837, six years before Samuel Morse completed his telegraph.[16] Failure often indicates perception of opportunity. One sign of a promising technology is the presence of start-up, established and venture capital firms, drawn like moths to a flame, attracted by the promise of potential profit. In the 1970s, over forty firms piled in to manufacture light-emitting-diode digital watches after Seiko pioneered the new product.[17]

The first iterations or appearances of new technologies often do not succeed practically or commercially. Many functional products do not succeed in the market, sometimes for reasons that have very little to do with their own attributes or flaws. For example, many operating systems for personal computers appeared in the late 1970s through early 1980s, including CP/M and Valdocs before the industry standardized around Microsoft DOS and Windows. Understanding why the vast majority of these approaches failed may often prove as informative as understanding why the telegraphs of Morse and Wheatstone and Microsoft's MS-DOS triumphed.

Many, if not most, technologies went through several unexpected iterations before a commercially viable version emerged. One of the more interesting American examples is the steamboat, attributed first to Robert Fulton and his *Claremont* in 1807. The reality is that several inventors – including John Fitch, James Rumsey, and John Stevens – preceded him, but failed primarily due to a lack of resources and American-made steam engines that proved inadequately powered and unreliable. Learning from their mistakes, Fulton used British engines and allied himself with Robert Livingstone, who provided essential economic and political support.[18]

Who defines a failure? The promoters or critics of a technology or more neutral observers? Is the label "failure" primarily a rhetorical device or can it provide more understanding of the process of technological evolution? Rhetoric is important: Technologies develop in an atmosphere of hope and hyperbole, which come from great expectations and excitement about what the technology can do, and, especially for radical technologies, how they will affect society.[19] Most ventures fail, but enough succeed spectacularly that hope continues to rise eternally in the hearts and prospectuses of entrepreneurs. Such enthusiasm is needed to create the enormous effort to develop and market new products. An accurate balance sheet would probably scare many potential supporters away. The greater the excitement, however, the greater the potential for a gap between reality and expectations. Rising expectations may also contribute to a technology's failure by raising the criteria for success. What would have been spectacular in 1965 was considered inadequate in 1980. As Ruth Schwartz demonstrated in her study of household technology, the increasing capabilities of a technology raised expectations of what the technology should do.[20] And failure for whom? The Chunnel under the English Channel was a dismal financial failure for its investors, but a boon for the millions of people who quickly traversed between London and Paris in the comfort of a train.[21] Similarly, states that invested in canals in the mid-19th century and people who invested in airlines in the 20th century often lost money, though the canal users and airline passengers benefitted.[22]

In addition to these theoretical issues, studying failure faces two major practical problems. First, people and organizations do not like to discuss their failures.[23] Similarly, journalists and other contemporary chroniclers tend to write more about successes than failures. Second, failed projects and companies may disappear so records may be hard to find. Sometimes, the only trace of a pioneering firm is a small newspaper or trade press article, printed verbatim from a press release, or a government tax form.[24] This means historians must be creative in their search for information.[25] One consequence is that government failures tend to be more studied, partly because data is often more available and partly because a waste of tax dollars tends to receive more attention than a waste of corporate dollars.

There are three basic types of failure. The first is the failure of new technologies to succeed against existing technologies. Sometimes, like Thomas Edison's concrete houses, the failure is so convincing that the technology essentially disappears.[26] More often, the original or new promoters try to improve the technology and bring it to market again. The failure of Apple's Newton did not deter other firms from developing and introducing handheld computers, such as the very successful Palm PDA.[27] The second type is the failure of existing technologies under new conditions. Sometimes the technology, such as a voting machine or ballot, may have known flaws, but they are considered minor compared with the expense of fixing them. Not until unusual stress occurs, such as an essentially tied electorate in Florida in 2000, do the flaws cause the technology to fail.[28] The third type is the failure of old technologies to compete successfully against new technologies. The definition of failure here is less the actual replacement but instead how well the decline is managed so that the company survives, the old technology remains useful until either it disappears or finds a niche, and users are content. A contemporary example is the shift from film to digital cameras. To some extent, Kodak and Fuji Photo have succeeded in the new realm, even as their old market of film and cameras has shrank beneath them, far better than competitors like Agfa and Minolta.[29]

3. Failure of the New

New technological products are complex social, economic, and political constructs that emerge from negotiations among various actors inside and outside the sponsoring organization. Technologies do not just emerge like Athena, fullblown from the head of Zeus. As they progress from idea to reality, technologies are pulled, pushed, shaped, mashed, prodded, poked, shifted, cajoled and otherwise subjected to the actions and inactions of people they touch. Every attempt at promoting a new technology has its entrepreneurs, supporters and patrons, observers, competitors, regulators, and customers. Creating and maintaining such a network of involved and committed supporters, as John Law and Michel Callon have demonstrated, is extremely difficult yet very important for success.[30] There are almost always alternatives at every step. Choosing among competing options is challenging and best done with hindsight.

Expressed in terms of actor network theory, failure is a way of discovering erroneous perceptions about a network and its environment: Some actors may actually have less or more influence than expected while other actors may have been completely unpredicted. Only very late in the development of the Segway, for example, did Dean Kamen's team realize they needed to check if city laws would allow the self-propelled, self-stabilizing vehicle to use sidewalks.[31]

To have a chance to succeed, a new technology must overcome five basic challenges: technological, material, competitive, operational, and environmental. These challenges are linked together, not sequential obstacles to be overcome once and then ignored. A primary reason for failure is underestimating these challenges. First, will the technology actually perform as promised? Can the technology evolve from a laboratory experiment into a practical device or service? Different actors may have different definitions of "practical," definitions that may change over time. Will it work in a new environment, whether physical or institutional? An important concept is technological prematurity, a situation where the actual technology functions poorly in its desired application. The underlying concepts may be sound, but the implementing technologies are not. The prematurity refers to the product not working adequately in its chosen market. Sometimes, the deficiencies are not discovered until the product leaves the controlled environment of the laboratory and enters the messy, unpredictable real world. Two prominent examples are the Diesel engine, which needed two decades of intensive technological and institutional evolution before it succeeded commercially, and software, whose developers often use feedback from early releases to revise and reintroduce their products.[32]

Sometimes these premature prototypes were pushed onto the market earlier than their developers wanted, the result of overeager promoters, anxious investors, and the threat of competing products. One solution was to redefine the audience, usually from a larger, competitive market to niche markets where the technology received greater resources and support, giving it an opportunity to mature and develop. These protected environments allowed a fragile and costly technology to survive while it evolved into a more capable, competitive, and robust product.[33] Misunderstanding (or not fully understanding) the physical environment may contribute to failure. Failures, often dramatically demonstrated by exploding rockets, were constant reminders in the early years of space exploration of how incompletely the environment of space was understood and how demanding that environment and the needed technology were.

Second, if the technology does work, does its creator have enough resources – financial, human, and other – to develop and bring it to market? Battles inside an organization occur for resources to develop and bring a product to market. There are never enough resources to do everything; projects compete with other projects for equipment, funding, and other resources. Nor does a new product proceed without encountering resistance. Opposition — or a simple lack of support — can come from many sources such as proponents of other projects and technologies, accounting departments worried about shareholder attractiveness, conservative management, an organizational restructuring, or a fractured corporate structure.[34] One problem of startup firms is they often run short of money before their product is mature enough to be sold. If judged by its consistent ability to lose money, Amazon.com was a failure for its first six years. A major difference between Amazon and other dot-com startups was Jeff Bezos' ability to continue to raise the enormous funds to cover Amazon's losses of over $1 billion before it turned its first profit in 2001.[35]

Third, if the technology reaches the market, it probably will face competition from other technologies and competing versions of the same technology. Will it work as well if not better than competing technologies? Are its economic costs less than its competitors? The choice of a power source for the automobile in the late 19th and early 20th centuries was a contest among the steam, electric, and internal combustion engines. Recent research has shown that the triumph of the gasoline engine was not inevitable: Proponents and users of steam and electric vehicles were not irrational and impractical. As Wiebe Bijker has written about the shaping of the bicycle, social factors were as important as technical factors in failed versions. Often awareness about or developing such factors differentiated the surviving from the failed firm.[36] Competition among products for the same market is more obvious because it is usually conducted in public, such as Boeing and Airbus vying for commercial passenger aircraft. Sometimes technological differences (such as range and capacity) dominate decision-making, but often non-technical factors, such as cost, financing, perceived need, and fit with existing infrastructure, play a determining role.

Fourth, users may not like the technology and prefer alternatives, if given a choice. Many users of technology are not the actual customers. Office staff are rarely consulted on the equipment and software they use, nor are automobile drivers asked about types of parking meters. How well does the new technology fit into a user's existing procedures and operations? E-mail systems began appearing in the late 1970s, but encountered major user resistance because of the many incompatible systems, difficulties in learning how to use them, and limited formatting and graphics.[37] The problem of incompatibility was so bad that General Motors had to introduce a special interface, Diamond, to link its eight internal incompatible email systems.[38]

Fifth, is the overall environment conducive to the new technology? What happens if political, economic, or social conditions change? A recession may sharply reduce the amount of capital available to develop or acquire a new technology.[39] New events may suddenly create demand for existing or new products. In the 1990s, Motorola and other investors lost billions of dollars developing Iridium, a network of satellites that promised mobile communications anywhere in the world. Iridium went bankrupt because the unforeseen development of mobile phones provided a less expensive alternative for most people. After 2002, however, the new need for the American military to communicate within Afghanistan and Iraq turned the newly reformed Iridium into a profitable concern by providing a major market.[40] Sometimes, completely unexpected events can destroy a firm and its technology, such as the death of a patron. The history of computing might have been different if Henry Strauss had not died in a plane crash in 1949. His death deprived the Eckley-Machley Computer Corporation of its exchange for a 40% interest. The company soon recalled its loan, which led to the demise of the pioneering computer firm.[41]

4. Facsimile and Failure

The history of the fax machine provides an abundance of examples showing the importance and continual presence of failure in the evolution of a new technology. First patented in 1843, faxing did not become a major commercial success until the 1980s, over 140 years later. If facsimile was such a good idea, why did it take so long to succeed commercially? Certainly it was not for lack of trying – over the decades well-known inventors such as Thomas Edison and Eduoard Belin and little-known inventors like Frederick Bakewell and William E. Sawyer, established firms like Western Union and myriads of startups developed fax machines. The overwhelming majority failed. The first fax machine was built in 1848 in Britain. The first scheduled services appeared in France from 1863 through 1871. In 1900s-1910s, the first transmission of photographs occurred in Germany. In the 1920s-30s, national postal authorities and American telecommunication firms like ATT and RCA, introduced commercial services. By the mid-1930s, newspapers routinely faxed photographs. The first tentative efforts to introduce faxing for office communications began in the 1930s, but not until the late 1960s did dedicated business machines appear from American firms. Two and a half generations of analog equipment did not create the expected huge market. Instead, Japanese firms introduced new digital equipment in the 1980s, which, aided by the new G3 standard, finally turned the fax machine into essential equipment for the office.

Reflecting the competitive nature of faxing, failures often occurred in clusters — such as selenium/photocell-based fax transmitters in the 1890s-1900s and fax service companies in the 1960s-70s. As happens in science, several people developed similar ideas at approximately the same time, demonstrating the importance of a shared environment and perspectives: New technology may seem (finally) mature, a market (finally) appears ready for a new service, or professional and public interest becomes drawn to new areas of expectation, thus attracting attention and resources. Throughout fax's long history, optimism and great expectations continued to prevail. Cognizant of previous failures, advocates knew that this time they would get it right; that this time, faxing would finally succeed. These engineers and entrepreneurs cannot be accused of having blinkered eyes: Proponents recognized economic feasibility was as essential as technical feasibility. How then does one account for their continued failures? Or for the willingness of patrons to sponsor yet another effort?

The image that comes to mind is a World War I battlefield with the dead and wounded of the previous charge out in front, and the next wave of soldiers preparing to go over the top into no-man's land. Why was there yet another line of firms eagerly throwing themselves over the top to encounter the machine-gun harsh reality of a skeptical, small market? What motivated individuals and firms to commit resources to create new markets and technology, given that daunting history? Of answers stated and unstated, the most important was "This time it will be different." Promoters of a new product or service explained that previous failures occurred because the machines were too expensive, too slow or otherwise inadequate. This time, promoters claimed, they had improved the technology, improved the economics, were taking advantage of a new, more hospitable environment, and so forth. Often those claims were true – but not significant enough to enable success. But if those faults were recognizable after the fact, why not earlier? What would make later attempts more successful than previous efforts?

Indeed, it is striking how clearly inventors understood the obstacles they faced, possibly because many 19th century experimenters had successful telegraph inventions to their credit and they understood telegraphy's weaknesses.[42] Inventors and ideas flowed easily between faxing and telegraphy and later with the worlds of telephony and computers. Most developers set specific benchmarks for comparison. William E. Sawyer, for example, stated in 1876 that a successful copying telegraph should perform as quickly as a Morse system (then 25 words per minute), use ordinary paper, and not demand expensive and complex equipment.[43] Thomas Edison promised his system would equal Morse's in speed, transmit "outline Photographs" and any language, retransmit the chemical strip of a received telegram, demand no special preparation to send messages, and be simple, reliable, fast, and practical.[44] Two strands of failure consistently weave in and out of the history of faxing. First, proponents and investors constantly underestimated the technological and financial challenges of developing equipment. Second, even though the capabilities of fax machines improved over time, faxing competed poorly with competitors – primarily the letter, telegraph, telex, telephone and ultimately e-mail, which also improved technically and usually were less expensive and easier to use.

Faxing's evolution encountered all five types of challenges, technological, material, competitive, operational, and environmental. The most basic was technological. Fax machines reflected the state of electrotechnology and were considered a high technology of the time. What held true in 1947 was equally true in 1847, as *Electronic Engineering* noted, "Perhaps the most important factor in a really first class Picture Telegraphy system is the standard of mechanical design and workmanship which goes into the scanning and optical systems."[45] The actual machines were complex electromechanical marvels, essentially made by hand by camera and precision instrument makers through the 1930s. The inability to machine parts, such as gears, to sufficiently high precision persistently dogged designers.[46] The "extreme delicacy" of Arthur Korn's groundbreaking machines to transmit photographs in the 1900s-10s meant the equipment was expensive to build and difficult to maintain and operate.[47]

If the essence of engineering is controlling the environment, then facsimile suffered from bad engineering. The systems required frequent, delicate adjustments and manipulation by their operators.[48] As important as improving the fax machines was manipulating the telephone, telegraph, or radio circuit. The demands of facsimile sparked research into understanding and measuring these environments as well as theoretical studies on information. Applications pushed research.[49]

Users' desired goals of easy operations, low cost, good quality copy and high speed changed remarkably little over time; what did change were expectations as the technology advanced. Early photographic transmissions demanded over an hour and were considered amazing accomplishments in the 1910s. Six minutes for a page was standard from the 1930s through 1970s, only to be replaced by three-minute machines in the 1970s which in turn were replaced by subminute equipment in the 1980s. Similarly, expected resolution rose from 60 to 96 to 200 lines per inch over time.

Failure can indicate differences over which technological path to pursue. Sometimes, following the more promising path resulted in technological prematurity as the prolonged and tortuous development of subdigital faxing illustrates. In the early 1970s, the most important technological question was whether researchers should try to leap from analog six-minute to digital subminute machines or instead pursue the less challenging path to a three-minute analog machine. The attraction of subminute faxing was a greater pool of customers, who wanted the speed. Four overlapping waves of attempts to create subminute machines occurred between the mid-1960s and mid-1980s. Many were the Loch Ness machines, whose existence was rumored but never surfaced. Only a few machines moved beyond the prototype stage. The small first wave, comprised of small firms like Shintron or startups like EIS, vanished by 1971.[50] The second wave by firms already offering machines, ended in 1974. The third wave in the late 1970s featured tenuous footholds by domestic and Japanese firms with incompatible equipment. Not until the fourth, successful wave began in the early 1980s with the first G3 machines did subminute machines finally fulfill the promise of their promoters.

The technologies Graphic Sciences employed in its feasibility model — "laser technology, solid state imaging devices, complex MOS and bipolar LSI circuit technology, data compression techniques and flat bed scanning" — became standard features in the G3 machines that revolutionized faxing after 1980.[51] The differences between those successful versions and the failed attempts a decade earlier were due to cost and complexity. Quite simply, the technology and economics simply proved too daunting. As *Fortune* predicted in 1973, the high cost of the necessary electronics, "similar to that of a small digital computer" raised the price of a machine to $5,000-10,000, far beyond what most customers could afford.[52] The inability of startup firms to develop subminute machines had institutional as well as technological causes. Large firms with established sales forces and capital spurned joint ventures with small, innovative companies with radically innovative ideas.[53] Most importantly, market leader Xerox did not take advantage of several opportunities to buy, invest, or form joint ventures with small firms with digital and other advanced facsimile technologies.[54]

The late 1960s saw a wave of enthusiasm about faxing from promoters, an enthusiasm matched by potential manufacturers and investors. According to Howard M. Anderson, a fax industry analyst, 126 companies investigated manufacturing fax equipment and 32 actually tried by 1973.[55] Aborted machines littered the digital landscape.[56] Sometimes the corpses were only projects; other times, the failed efforts also destroyed the firm or the support of top management for continuing fax development.[57] The key resource was funding. Without it, patents, ideas, and engineering were worthless. Access to funding was a key factor in survival and accidents of timing – or ability to spot an opportunity arising. From the heady optimism about faxing of the late 1960s that allowed Graphic Sciences to raise $40 million, the received wisdom on Wall Street shifted by the early 1970s to the perception that fax was an unpromising market and money could be more profitably invested elsewhere. Their inability to raise enough capital meant EIS and Visual Science were purchased by Addressograph-Multigraph and MGCS respectively while Faxon never found the money to get to market. Without repeated infusions of external money, Dacom would not have survived long enough to metamorphize into Rapifax.

Finding resources could be a long and often futile effort. Information engineer Robert E. Wernikoff convinced several investors in 1963 that digital faxing could provide faster transmission and higher resolution compared with its analog counterpart. Initially operating out of the basement of defense contractor EG&G, Electronic Image Systems (EIS) developed a fax machine, the Telikon (from the Greek telis convey or transmit and ikon image) designed around data compression. Getting the subsystems to work and work reliably often proved more troublesome than the data compression. As EIS discovered, a complex technology was composed of many other technologies and integrating them was a major challenge. To keep the final cost affordable, EIS had to reduce the resolution and compression ratios.[58] Just as Telikon testing began in late 1964, EIS had to shift its focus from facsimile to survive.[59] Running low on cash, it bid and won a NASA contract to build four photofacsimile recorders for Nimbus weather satellites. The contract also came with extensive supervision and a never-ending flow of demanding documentation, neither desired by a small firm struggling to meet a payroll.[60] At one point, their "cash position, which is despairingly thin at best, curled up and died" and a only a personal loan from Wernikoff and his co-founder kept the firm alive.[61]

Lacking the financial, technical, and marketing resources to complete and promote its Telikon, a situation familiar to many startups, EIS sought an alliance with a larger firm to gain those resources, ideally by placing large orders or paying royalties for its patents. Wernikoff demonstrated Telikon to the copying firms Xerox and Bruning, the tape recording company Ampex, office equipment manufacturer A. B. Dick, and US Steel. Other firms were also interested including the *Wall Street Journal,* which considered EIS' compression logic for the newspaper's fax systems.[62] Unfortunately, interest did not equal income. For Wernikoff, life must have been schizophrenic, alternating between euphoric demonstrations that would have sold a hundred machines "if we had any to sell" and the depression of "endless visits, telephone conversations and strategic sessions" to sign a contract. Negotiations concentrated as much on the exclusivity of licenses, advance payments and royalties as the actual technologies.[63]

In 1966, EIS became part of Addressograph-Multigraph, a large office equipment manufacturer, which promised to commercialize the Telikon. The was no less risky. By 1971, of eight service companies established by 1969, one had gone bankrupt, six had severely retrenched, and only Vistagram Centers, a business of facsimile manufacturer Graphic Sciences, remained.[74] The technology worked, but the high cost of transmitting documents and the lack of an obvious need doomed these attempts.

A second wave of facsimile services by major telecommunications firms in the mid-1970s fared little better despite their attraction of enabling communication between incompatible and different types of equipment. A computer-mediated service so businesses could fax from their equipment to anyone else's equipment seemed an excellent idea, and several firms pursued such efforts. By 1983, these ambitious efforts had lost tens of millions of dollars and attracted only a few users. ITT's Fax-Pak was "the biggest facsimile debacle by a long margin," according to a market research firm, earned a maximum of $2 million annually on a $30 million investment. The services were expensive and difficult to use. Furthermore, most corporate faxing, the desired market, was internal so incompatibility was less of a problem. The establishment of G3 standards in 1980, which enabled compatibility among different machines, finally undermined these services.[75]

Not all fax services failed. The most successful applications occurred in specific markets where customers were willing to pay for speed and convenience. Expediting permits for commercial trucks to enter a state was the best example of profitably filling a niche. Correctly sensing an opportunity, American Facsimile Services (AFS) in 1968 and Transceiver Service in 1971 offered their respective Insta-Com and Instacom Permit services. By 1976, these firms filed over a million permits annually, earning over $7.5 million.[76]

Less dramatic than the failure of individual firms but more important in slowing the diffusion of faxing was a major problem of competition within a technology, incompatibility. For networking technologies like faxing, the ability to communicate between different equipment is essential. Until a standard emerges, incompatible options will keep the market smaller than expected because customers will be cautious, fearful of choosing the wrong version. The smaller market means production will be smaller and more expensive, thus reducing the financial attraction to use the new technology. This vicious circle hurt the growth of fax in the 1960s-70s as competing firms introduced incompatible equipment. The Xerox FM equipment could not communicate with the Graphic Sciences AM machines. Eventually, manufacturers produced some equipment that was mutually compatible, but those machines were more expensive (and complex) than standard equipment. Several firms offered products or services to link incompatible machines, but these offerings also were expensive or hard to use. The result was a smaller, divided market that delayed the spread of faxing.

One of the most interesting failures was the radio-broadcast facsimile newspaper. Between 1935 and 1950, newspapers, radio stations, and fax promoters cooperated to create the "newspaper of the future." The concept was simple: Instead of broadcasting sound from a studio, a radio station would scan a specially prepared newspaper and transmit it over the airwaves to a printer in the home. Similar attempts in 1989-91 also failed. The fail stemmed partly from technological inadequacies but more from poor economics and misconceptions about the demand for news and the popularity of television.

Although several inventors and firms developed equipment, the largest player was the Radio Corporation of America and the fax engineers working under Charles Young. From the beginning, RCA researchers never separated the technology from commercialization. For example, in 1932 Young's Facsimile Section estimated that a fax receiver would cost from $93.00 in a production run of 1000 to $58.07 for a run of 50,000. Adding an AM radio and loudspeaker to the latter would add $19.70. The estimated price for consumers was $250. For comparison, a teletype printer cost $350.[77] Left uncompared were the few cents of a newspaper or several dollars for a basic AM radio. In October, 1937, the Federal Communications Commission (FCC) began receiving requests to broadcast fax papers after midnight.[78] The FCC licensed over twenty stations by mid-1938 and forty by 1939. The number of stations actually transmitting, however, dropped to sixteen in 1940 and only four a year later when World War II halted the tests.[79] The loss of interest came from technical and commercial shortcomings. The printers made poor copies and took an hour to transmit four pages. A morning newspaper provided far more news at far less cost.[80]

After World War II, fax broadcasting experienced a rebirth based on FM transmission, which offered significantly better broadcasting quality and faster printing than AM though fewer existing customers and advertisers. Radio Invention's Elliott Crooks predicted that a year after FCC authorization, the nation would have 100 fax publication ranging from small audiences with less than 10 recorders to stations serving 10,000 recorders.[81] Instead, less than a year after the FCC authorized commercial fax broadcasting in mid-1948, the dream of commercial fax broadcasting was dead.[82] Audiences had flocked to demonstrations, but refused to follow with their money. A May, 1947 poll by The Philadelphia Inquirer of 945 people who viewed its public demonstrations found, unsurprisingly, that their interest faded rapidly with price. Sixty-four percent would pay $100, 31% would pay $200, but only 6% would pay $500, still far below the actual price of a receiver.[83]

Economics as well as a technology still being tweaked destroyed the feasibility of fax. Without mass production to lower the cost of receivers and advertising to generate income, no one expected fax broadcasting to succeed. The initial FM fax receivers, designed to generate public interest and elite acceptance, cost $800-900, far above the cost of a television and newspaper.[84] In a chicken-and-egg situation, the mass production needed to establish a market never occurred because the market did not exist. Since transmitting costs essentially were the same for 30 or 30,000 receivers, a niche market could not develop and expand.

The problem with the faxed newspaper was not just the technology but the nature of its perceived market. Even with trouble-free faxing, the faxpaper could not compete against television, radio, and other forms of instant news, as the short life of the modern faxpaper illustrated. On April 3, 1989 when the *Hartford Courant* launched its one-page FaxPaper, an afternoon summary of the next day's paper for local businessmen and insurance executives.

Initially priced at $2500, the subscription soon steeply fell to $1500, then $600 in a continual effort, backed with aggressive marketing, to gain paying readers. The paper had 2000 subscribers in 1992, before ceasing publication in 1993.[85] Far less successful and more typical was the five-month existence in mid-1990 of the *Chicago Tribune's* fax paper. Lack of subscribers and advertisers here, as elsewhere, pulled the plug.[86]

A 1991 survey by the American Newspaper Publishers Association (ANPA) of faxpapers found fifteen efforts, four of which had already died. Two-thirds had been launched in 1990.[87] By 1992, owners had discovered that condensed versions of their regular papers, lacking in graphics and length, were a recipe for failure. The lack of subscribers was matched only by the lack of advertisers. Like fax services, the successful attempts found niche markets. The first was geographical, offering an abbreviated newspaper where it would not normally be available, such as a cruise ship. The second niche was the specialized newsletter, providing information of interest only to a few people, such as fans of Ohio State University football. The third area was as an adjunct of a newspaper, providing additional information to callers such as stock quotations and restaurant reviews.

Changes in the environment also affected the evolution of fax. Sudden economic changes, particularly recessions, were the largest unplanned and undesired events adversely affecting fax. The 1973-74 recession forced the cancellation of thousands of leases and thus "changed the face of the fax market more than any other event" and not for the better. Xerox rentals alone fell from approximately 60,000 to 45,000 machines, and did not regain pre-recession levels until 1978. With thousands of their machines being returned, firms focused more on trying to maintain their existing markets than introducing newer, more expensive machines.[88] Not all changes were economic or negative. In the late 1980s, the International Telecommunications Union, the main international standard-setting organization for communications, radically revised its procedures. Instead of demanding four, eight or more years to introduce a new protocol, the new rules enabled new features to become part of the upgraded G3 standard in only a year.[89] Consequently, new capabilities spread rapidly through the fax world, encouraging innovation and increasing the capabilities of faxing, thus extending its attraction.

Sometimes, a new technology manages to fail multiple challenges. Federal Express conceived ZapMail not as technology for technology's sake but to further sharpen the company's competitive edge by expanding from the physical to the electronic delivery of documents and possibly data, voice, and video.[90] Federal Express had high expectations. In 1984 the company estimated ZapMail's total cost at $1.2 billion over ten years but revenues at $1.3 billion in 1988 and $3.5 billion by 1993. As Federal Express earned $1.4 billion in 1984, it anticipated considerable financial rewards.[91] ZapMail consisted of two tiers of service. Low-volume customers would receive regular delivery and pickup but the documents would be faxed between Federal Express offices for door-to-door delivery within two hours. High-volume users would have their own Federal Express ZapMailer fax machine. Ultimately, two clients' roofs.

ZapMail had four flaws: high cost compared with competing services, normal teething problems, a focus on the mailroom instead of the actual sender, and incompatible G4 equipment. An obvious problem was the high initial charge of $35 for five pages, a rate that contrasted unfavorably with $14 for Federal Express' overnight delivery and 22 cents for a letter.[92] The "normal" types of technical problems included software difficulties and delays in receiving equipment, including its fax machines and satellites, which never were launched.[93] More fundamentally flawed, however, were ZapMail's incompatibility with G3 machines and emphasis on centralized mailroom to mailroom delivery at a time when the trend was towards decentralized desktop to desktop delivery. Indeed, Federal Express's prior success in overnight delivery was based on bypassing mailrooms for direct desktop to desktop delivery. Moving its focus away from the desktop back to the mailroom seems, in hindsight, inexcusable. More understandable was using the technologically advanced G4 NEC ZapMailer, which was much faster than but incompatible with G3 machines. The company hoped to establish a fax monopoly equivalent to AT&T's hold on telephone service. Federal Express realized its error in 1986 and started retrofitting its ZapMailer II machines with a G3 capacity and offering a less expensive G3 machine, but these actions were too late.[94]

Customer demand never reached Federal Express's expectations. Deliveries averaged slightly over 2300 daily transmissions in its first year, contributing less than one percent of the firm's income.[95] Companies sent fewer same-day deliveries than expected. The three-hour difference between the east and west coasts, coupled with the delivery time from mailrooms, restricted the window of transcontinental transmissions to a few hours a day.[96] By 1986, ZapMail reached its maximum volume of 11,000 documents daily. While impressive compared with previous fax services, Federal Express was judging – and paying – by different criteria, such as the 550,000 packages it handled daily.[97] Financially, ZapMail's costs and losses escalated even as Federal Express revamped the service. In fiscal year 1986, ZapMail, on revenues of $32 million, lost $132 million, an amount equal to the firm's profit. When Federal Express finally pulled the plug on ZapMail in October, 1986, it had lost $317 million.[98]

5. Coping with Failure

Some fruitful paths for future research include how individuals and organizations cope with failure, institutionalized partial failures, and cultural differences in dealing with the consequences of failure. If failure is indeed a normal part of the evolution of technology, its practitioners must have developed ways to deal with it. Upon examination, the history of technology reveals a rich world of formal and informal mechanisms that individuals, organizations, and firms use to learn from failure, avoid future failures, and minimize its consequences. The larger and more bureaucratic the organization, the more elaborate its procedures will be. Internal and external reviews will assess their future technologies at various stages. A R&D laboratory, for example, may decide what lines of development to pursue — or not. As the technology matures and its costs increase, its future within that organization is usually subject to increasingly formal and higher level scrutiny. These internal and external reviews and analyses are designed to reduce the chances of failure by establishing that known challenges are understood and surmountable. Harder to study but more common are the informal mechanisms of organizations. Firms may also maintain internal databases, possibly on a formal basis but often organized informally at a local level.[99]

Many of these reviews focus narrowly on the actual technology. Larger economic and environmental challenges, which are harder to estimate and predict, are often ignored. Consequently, going outside the organization for a more impartial perspective is a well-known mechanism. Market research firms can provide guidance and suggestions, providing general information about the expected market for a new technology as well as specific information about competitors. Some organizations engage in creating scenarios to test their plans under different assumptions, including very different political and economic environments.[100] Reviews and studies can only help so much. Before introducing a new technology or service, firms may test it with a small group of users or in limited areas to gain feedback on its actual application. In software development, such "beta" testing is a normal procedure to find errors that escaped the firm's internal checks. One of the attractions of open-source software is a scrutiny of its code by many skilled observers.

The more intolerant an environment and the more serious the consequences of failure in it, the more likely organizations operating in those environments have developed procedures to analyze and minimize failure. Unsurprisingly, the aerospace industry has the most comprehensive mechanisms. The consequences of an equipment failure in an office are usually minor; at 10,000 meters in an airplane or in outer space, a failure can be fatal. One way of avoiding technical failure is for an outside agency to certify a new technology as safe before it can be used. Commercial aircraft must receive flightworthiness certificates by government agencies before being legally able to fly.

The American space program offers one of the best areas of investigation for several reasons. First, failure occurs surprisingly often: The early years of space launches saw failure rates of 50% and the failure rate of launches since 1980 is 6%.[101] Second, the federal government is usually involved, so documents are usually preserved and, if not classified, accessible. Third, the failures are often visible disasters — think of the shuttle Challenger exploding after launch, so public pressure exists to understand the causes. Forth, the aerospace industry has developed procedures to understand failures and to learn from them.

Before a National Aeronautics and Space Administration (NASA) mission is launched, it has survived several rounds of testing and mission reviews. One inherent problem with such procedures is a negative feedback loop: The more elaborate and formal an organization's procedures to mitigate risk, the greater their complexity and cost and, possibly, the chances launcher fails, NASA establishes an investigative panel to determine the cause. For truly high-profile failures, such as the loss of a space shuttle, the White House established independent commissions to ensure their findings are not biased to protect NASA. The panel's findings often call for institutional changes to ensure those causes of failure will not occur again.[103]

Taking on too much risk can lead to failure, but avoiding too much risk can lead to a failure to invest in the future.[104] The history of technology is filled with firms which rejected opportunities to introduce or invest in new technologies that eventually challenged their existing markets. Western Union rejected opportunities to purchase the patents for the telephone and the typewriter while "one of the greatest errors in the history of high technology" was National Cash Register's refusal of the Navy's offer to fund its entry into the computer business after World War II.[105]

One way of guarding against failure was to reduce expectations and risk by following a path of incremental innovation, one small step at a time. Conservative approaches to new technology may produce incremental changes, significantly reducing the chances of failure but also the possibility of major improvements. A policy of incremental improvements, however, may be less traumatic and more successful than seeking major jumps in new technologies.[106] Too conservative an approach, however, may result in organizations that lose their ability to develop new technologies. One indication of such a hardening of an institution's ability to handle new technologies is the creation of new units to do what the institution is not doing. Two such examples are the Defense Advanced Research Projects Agency of the Department of Defense and the Saturn division of General Motors (GM), established in 1985.

In 1958, the Department of Defense (DOD) established the Advanced Research Projects Agency (ARPA) partly in response to political pressure created by the emerging Space Race, a race in which the United States appeared increasingly behind the Soviet Union. Another reason was the belief the military R&D system was increasingly conservative and unable to respond rapidly to new challenges. DARPA was supposed to take risks and it has, including funding the development of a communications system to survive a nuclear war, a system that would become the internet.[107] Saturn represented such a major shift in manufacturing cars that GM could not introduce it within its existing divisions. Instead, the gigantic firm established a separate organizational unit and built the first Saturn plant in Tennessee. These arrangements ensured that the lessons of the new approach would not easily spread to other parts of the corporation.

Another way of reducing risk was to work with another firm to develop or market a technology. Joint ventures may harness the resources of different organizations synergistically — or prove a disaster if the participants cannot work effectively together. The reasons for unsuccessful collaborations range from the cultural and institutional to disagreements about resource allotment and paths to follow.[108]

Some types of partial failures have become institutionalized, especially complex, high technology projects. Partial failure includes projects that are significantly over budget, behind schedule, and often result in a product built in fewer numbers (due to higher costs) or with lesser capabilities. Reports and studies on these problems – reducing the rate and severity of failure – have appeared for decades with regularity but no lasting results. The chronic persistence of such projects in military and aerospace technology raises the question of how much of these problems are built into the management system that authorizes and administers them and how much are due to "pushing the envelope," to maximizing the performance of a new product with insufficient attention to economics and potential problems. These problems occur in many complex, high-technology projects. The Airbus 380 and Boeing 787 both encountered (and in the latter's case continue to encounter) significant problems in early production, resulting in delays, cost overruns, and other problems. Nor are they limited to physical products. Developing and integrating software has become so challenging that it become a major cause of technical delays and cost overruns. Indeed, the expectations about software are rather unusual for a product: It may be so difficult to learn or use that assistance is available, will definitely have defects,, and will be upgraded to fix the latest batch of known defects.[109]

Studying the consequences of failure may illuminate different cultural approaches to risk-taking and innovation. The differences may between societies – compare the American and European perspectives on startup firms, but also among different types of technology. Some industries are more risk-taking – and consequently court a higher chance of failure – than others. The high technology industries of Silicon Valley are a prime example where the environment encourages major as well as minor technological advances while also accepting greater chances of failure. The rapid appearance and disappearance of firms, the shifts of people between firms, and the focus on startup firms form an environment which minimizes the personal cost of failure. In contrast, the electrical utility industry since the 1960s had a reputation for conservative, incremental advances.[110]

6. Conclusion

Failure has received neither the historical nor analytical attention its importance deserves in the history of technology. Most histories focus on success, yet failure is normal for technologies and businesses. Companies and people that promote new technologies do not expect to fail, but many, if not most do. The historical neglect of failure can be partially remedied by greater attention to it. Of particular interest is studying how individuals and organizations have evolved strategies and tactics to minimize failure and its consequences. Greater analytic appreciation of failure, however, will demand the development of more theoretical approaches to understanding failure. Historians of technology need to work with sociologists, economic and business historians, and other academics to deepen our conceptual understanding of the many manifestations of failures. Historians also need to include concepts of risk and risk avoidance in understanding how individuals and organizations decide whether to develop particular technologies. Avoiding risk may be as effective a strategy for failure as seeking too much risk.

Failure is an integral part of a technology's evolution, a part that should not be forgotten or excluded. Just as honest biography is more interesting and valuable than an admiring hagiography, so too does the history of technology benefit from a fuller understanding of its subject. A complete history demands study and analysis of not only the roads taken, but also the roads not taken and the roads unsuccessfully taken as part of the tortuous, demanding, and uncertain path that technologies follow to move from an idea to a reality.

Acknowledgements

This paper benefitted greatly from discussion at a JASTS seminar at the University of Tokyo. This research was made possible by a Fulbright fellowship at the Tokyo Institute of Technology and the support of Texas A&M University.

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[75] International Resource Development, *Facsimile Markets* (1983), 62-5; International Resource Development, *Facsimile Markets* (1985), 59.

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[77] Charles J. Young, "Methods for Exploitation of Broadcast Facsimile," October 11, 1932, 2-3, 5. Neils Young collection.

[78] "Radio Would Print News in the Home," *New York Times* October 21, 1937, 19.

[79] *Seventh Annual Report of the FCC for 1941*, 37; Burton L. Hotaling, "Facsimile broadcasting: Problems

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[80] Panel 7, Committee 1 July 28, 1944 minutes, P7C1-393-A. Records of Radio Technical Planning Board Meetings, 1942-1948. Panel 7. Record Group 173, Box 3, National Archives.

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[95] George Moreland Stamps, "The Next Generation of Facsimile and the Electronic Communicating Copier," IGC Conference on Intelligent Copiers/Printers, Monterey, California, October 19-21, 1986.

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[98] Calvin Sims, "Coast-to-Coast in 20 Seconds: Fax Machines Alter Business," *New York Times* May 6,

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For an organization's attempt to extract knowledge from its employees, see NASA's Knowledge Management programs (km.nasa.gov/home/index.html (downloaded January 9, 2008).

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[101] David M. Harland and Ralph D. Lorenz, Space Systems Failures: Disasters and Rescues of Satellites, Rockets and Space Probes (London: Praxis, 2005); *NASA Pocket Statistics* history.nasa.gov/pocketstats/index.html (downloaded January 16, 2006); Wayne Eleazer, "First flight facts," *spacereview.com* May 8, 2006 www.thespacereview.com/article/616/1 (downloaded May 15, 2006).

[102] One aspect of avoiding failure is judging risk accurately, an activity people perform surprisingly poorly. When NASA began its human space flight program, a very contentious area was how to assess risk (Lloyd S. Swenson, Jr., James M. Grimwood, and Charles C. Alexander, *This New Ocean. A History of Project Mercury* (Washington, DC: GPO, 1998), 167-81).

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[104] Some funding agencies are concerned that they are becoming too conservative, funding only applications with a very high likelihood of success instead of riskier, but higher payoff applications.

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