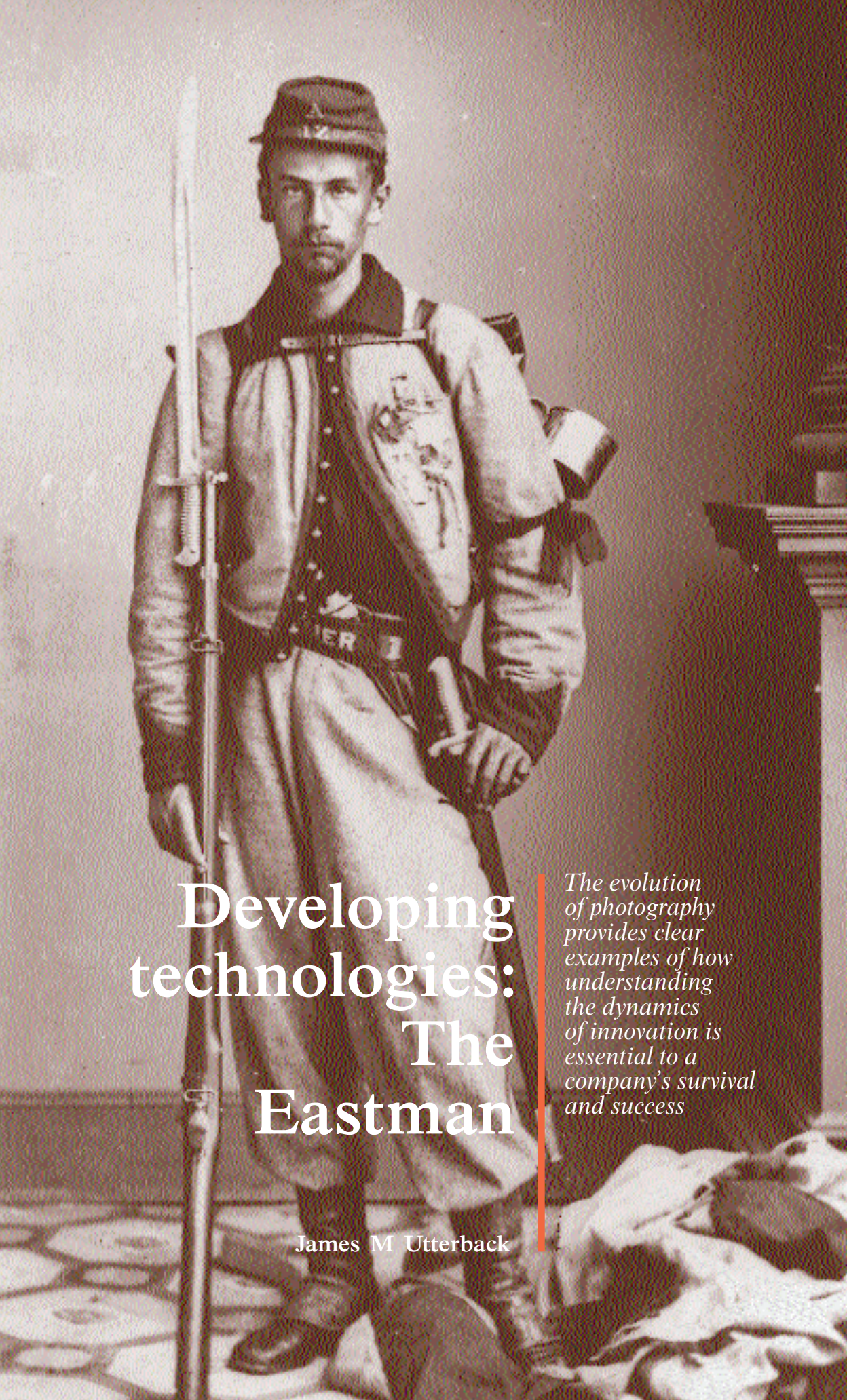

Developing technologies: The Eastman

The evolution of photography provides clear examples of how understanding the dynamics of innovation is essential to a company's survival and success

James M Utterback

TECHNOLOGICAL INNOVATION CAN RESHAPE the competitive landscape of an entire industry with astonishing speed. Established businesses may fail to bridge the discontinuity and wither away, while newcomers with novel concepts or methods rise to dominance. Industry after industry exhibits similar patterns of transformation when a new product or process technology emerges to challenge old formats. A look at one industry* in which innovation has historically represented the key to success can throw light on these patterns and help identify the qualities that determine whether a firm will survive the encounter with dramatic technological change.

The photographic industry

Anyone who watched the Public Broadcasting Service series, *The Civil War,* first aired in the US in 1990, must surely have been struck by the hundreds of photographs used by producer Rick Burns to acquaint us with the history of that dramatic conflict. The images of generals, private soldiers, battlefields, and the war's hapless victims played across the screen as a background to interviews with historians and readings from letters and diaries of the period. Most of these pictures were remarkably vivid, despite the fact that they were taken with equipment based on mid-nineteenth-century technology. Indeed, by the time of the American Civil War, the technology for producing photographic images was two decades old, widely disseminated, and had already entered its second wave of technical innovation.

MATTHEW BRADY/RANGE/BETTMANN

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* Selected from a total of five case studies examined in *Mastering the Dynamics of Innovation.*

From copper plates to wet and dry glass

The origins of the photographic industry can be traced back to 1839 and the development of the daguerreotype in France. This method of producing images on sensitized silver-coated copper plates was an instant hit in the United States, spawning a small industry of practitioners, suppliers, and manufacturers. Samuel Morse, who later invented the telegraph, took the first-ever photograph in the western hemisphere that same year. As early as the mid-1840s, a small chain of portrait studios had been established in major cities across America.

By the mid-1850s, the daguerreotype had given way to a new technology that used a transparent and sticky substance called collodion to coat a glass plate. Just before shooting a picture, the photographer would photosensitize the collodion-coated plate with silver nitrate. When the glass was exposed to light, a negative image could be developed on it, "fixed" in a darkroom, and then printed onto photosensitive paper by exposing the glass plate and paper to bright sunlight.*

The barriers that prevented the expansion of photographic supply production were technological

The use of wet collodion plates greatly improved the photographic art. Though slow and unable to produce color, the technology provided images of a quality rivaling those produced today. A major drawback lay in the fact that the plates had to be sensitized and developed immediately before and after exposure. This required an abundance of equipment, a darkroom, and a fair knowledge of the underlying chemistry. Another drawback was the sheer weight and size of the dozens – if not hundreds – of glass plates that a photographer might use in a short time.

Taken together, the requisite chemical processes and the cumbersome methods of processing photographs limited the market to a cadre of professionals and dedicated amateurs. The barriers that prevented the expansion of photographic supply production – the perishability of photosensitive materials and the complexity of photography for the average person – were technological. The technological developments that were later to allow the photographic industry to grow to its full potential required a few intermediate steps. One such was the introduction of glass plates

* Here and at many other points in this article, I have drawn on Reese V. Jenkins' book *Images and Enterprise: Technology and the American Photographic Industry, 1839–1925,* Johns Hopkins University Press, Baltimore and London, 1975.

Other sources were Brian Coe, "The roll film revolution," in Colin Ford, ed., *The Story of Photography,* Century, London, 1989; Helmut Gernsheim, *A Concise History of Photography,* Grosset & Dunlap, New York, 1965; and Reese V. Jenkins, "Science, technology, and the evolution of photography, 1790–1925," in Eugene Ostroff, ed., *Pioneers of Photography,* Society of Imaging Science and Technology, Springfield, Va., 1987.

coated with a dry gelatin emulsion. This emulsion, introduced in the late 1870s, made it possible to produce nonperishable photosensitized glass plates in factories, thus making photography less complicated, more convenient, and cheaper, thanks to large-scale production of one of its key components. Dry plates were also "faster" than wet plates.

One of the many entrepreneurs to seize upon this innovation was a young amateur photographer from Rochester, New York named George Eastman. With a practical understanding of photochemistry, a little business experience, and the financial backing of a successful local businessman, Eastman started a dry plate supply company in 1878. Like its competitors, Eastman's Dry Plate Company sought to produce plates for a national market, and Eastman would be the first to develop the processes and equipment (stamping machines, ventilation systems, glass cleaning and coating machines) to achieve large-scale production. But unlike his competitors, Eastman was also among a handful who developed process improvements and production capabilities in a range of other photographic products: cameras, enlargers, printing paper, and assorted supplies.

Before long, dry plates took on all the hallmarks of a commodity business. The product was fairly undifferentiated to begin with, and as process improvements diffused rapidly within the United States, prices plummeted. The recession of 1854–55 helped drive many small plate manufacturers out of the business, leaving an oligarchy of producers, none of whom were making substantial money on dry gelatin plates.

Eastman had resolved to develop an entire *system* to change the picture-taking business

The availability of dry plates certainly simplified the job of professional photographers and serious amateurs, but it appears to have done little to broaden the market. Cameras remained large, bulky contraptions, the dry plates were just as heavy and breakable as the old wet ones, and a photographer still needed the wherewithal to develop and print from photo negatives. Eastman seems to have recognized this very early and, like Edison with incandescent lighting, he had resolved to develop an entire *system* to change the picture-taking business. Also like Edison, he would not start with a clean slate but would draw on the technological currents of his time. The coated dry plate technology provided the stepping stone to what he was seeking.

Film photography

As early as the late 1870s, Leon Warnerke, a Russian emigrant living in England, devised a camera system that operated like today's devices. A collodion tissue coated with a gelatin emulsion underlaid with rubber was

rolled up in the back of a camera. The tissue/rubber "film" was stretched across the area where the glass plate would normally go, and it was advanced as each picture was taken. The exposed emulsion was then laboriously separated from its rubber backing and affixed to a glass plate for processing.

Warnerke's system was clumsy and costly, and went nowhere. But its essential architecture was known to Eastman and his camera-designing associate, William Walker, and by 1885 the two had developed a special camera back with a roll film system, using a coated paper material that presaged the one that would eventually dominate the field. Their holder could be fitted to the back of a standard plate camera, and held up to 48 exposures on a roll.

This innovation represented a tremendous weight advantage over the glass plate system. But the paper roll film was a failure for Eastman, as it did not meet the standards of the professional market in speed, resolution, and contrast. So Eastman and his associates went back to their lab.

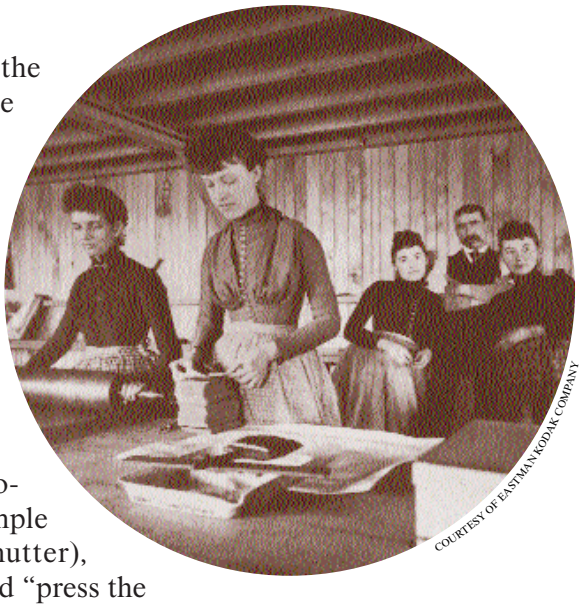
COURTESY OF EASTMAN KODAK COMPANY

Another technology of interest to the photographic industry at the time was celluloid. Invented in Europe during the 1860s, this plastic-like material had excited the imagination of a number of people in the industry in the 1870s and 1880s. The process innovations of two brothers from Albany, New York – John and Isaiah Hyatt – eventually served their interests. One breakthrough was a Hyatt mechanism capable of slicing sheets of celluloid as thin as one-hundredth of an inch; another was the development of a solution of nitrocellulose in amyl acetate that could be poured and dried into extremely thin sheets. The first suggested the substitution of celluloid plates for glass plates; the second suggested a still thinner film.

In his search for a material to replace glass, Eastman eventually turned to celluloid. It had properties that suited the purpose of providing a base for the photosensitive emulsion: it was lightweight, flexible, transparent, durable, and would not combine with the chemicals used in photo processing. What could be a more logical progression than to move from coating glass plates with a photosensitive emulsion to doing the same thing with a thin strip of clear celluloid?

Working with his chief chemist, Henry Reichenbach, Eastman succeeded by the spring of 1889 in developing a photosensitive celluloid film and the production processes to manufacture it commercially. At about the same time, he and his associates developed a simple and inexpensive camera, the Kodak, especially for using the new roll film. With film, camera, and production processes in place and coordinated, Eastman now had all the

elements he needed to break through the traditional boundaries of the photographic market.


COURTESY OF EASTMAN KODAK COMPANY

The success of the Eastman system

Having failed in his earlier attempt to sell roll film to professional photographers, Eastman now went after a market that had not yet responded to any of the innovations in photographic products: amateurs. The picture-taking system he offered them was simplicity itself. The novice photographer had to perform only three simple tasks: "pull the cord" (to cock the shutter), "turn the key" (to advance the film), and "press the button."

The Kodak camera came loaded with a 100-picture roll of film and sold for $25. Once the pictures were shot, the customer mailed the entire camera back to the Eastman company in Rochester, New York, where the film was taken out, developed, and printed, and the camera reloaded with film. The customer paid $10 for processing and the return of the reloaded camera.

The new system was offered to the public in the summer of 1888, using paper roll film, soon to be replaced by celluloid. It was an immediate success. The national photographers' convention named the Kodak the photographic invention of the year.

Eastman's first principle of business was to achieve production in large quantities through the use of machinery

With the development of this system, the two internal restraints of the technology – the perishability of photographic material and the complexity of picture taking for the average person – were effectively overcome. Photography could now make a quantum leap beyond the limitations of the professional market. Demand for Kodak cameras and film took off, and the company struggled desperately to keep up with it during the next decade. The development of production process improvements to manufacture the new celluloid film in large quantities became a major concern.

George Eastman had earlier shown himself to be astute in matters of process innovation. In fact, his first principle of business was to achieve production in large quantities through the use of machinery. From his early

invention of a mechanized system of cleaning, coating, and drying glass plates, he had also developed (with Walker) an ingenious system for coating and drying very long strips of photographic paper. These were later run over a roller that was partially submerged in a trough of gelatin emulsion and that coated the paper.

The very long strips of paper were suspended from the ceiling in serpentine loops (to save room) until the emulsion dried, then cut into individual sheets. Eastman was scrupulous in patenting every step of his manufacturing processes, as he understood their importance to the future success of his business.

Like photographic paper, roll film was a matter of coating, drying, and cutting; but those steps had to be preceded by the major step of creating celluloid from liquid ingredients. Initial production utilized the batch method. A solution of nitrocellulose and solvents was spread evenly over 12 glass tables, each 3.5 feet wide by 50 feet long, by a hopper and allowed to dry overnight. The next day, the resultant celluloid was coated with emulsion in darkness, stripped off the glass tables, and cut into long ribbons of film ready to be rolled.

By 1902, Eastman Kodak was producing 80 to 90 percent of the world's celluloid film

Increased demand induced Eastman to build a new research and film production facility outside Rochester in 1890–91. Here the same process was again employed, but the 12 tables were extended from 50 to 200 feet. Within a year, this capacity needed to be doubled.

Strangely, Eastman stayed with this batch method of film making and coating until the mid-1890s, five years after methods of continuous casting of celluloid had been achieved by the Hyatt brothers, and several years after a competitor, the Blair-Waterman Company, had developed the technology to coat and dry the Hyatts' film in a continuous process. Eastman's replacement for the departed Henry Reichenbach, a young MIT graduate named Darragh de Lancey, was instrumental in buying the patents and creating the designs that would allow Eastman in 1899 to successfully operate the first machine both to cast and to photosensitize continuous ribbons of celluloid film. Other machines were soon brought on line.

By 1902, Eastman Kodak was producing 80 to 90 percent of the world's celluloid film. By the 1930s, the company operated dozens of huge, specially designed film-making machines at its Kodak Park plant. The raw material for these was film "dope" – a solution with the viscosity of honey that was produced from cotton treated with nitric and sulphuric acids and dissolved in solvents (chiefly wood alcohol).

The film dope was spread over the polished surfaces of gigantic circulating wheels. Heat speeded the evaporation of the solvents, leaving a thin film of clear celluloid. The machines were designed to run night and day, turning out continuous ribbons of film.

The old technology reacts

While sales of roll film and roll film cameras exploded with the introduction of the Kodak system, neither glass plate photography nor the companies that supported it were condemned to rapid decline. Sales of dry gelatin plates held fairly steady for the next 15 to 20 years as professional studio photographers continued to favor the traditional system. Nevertheless, firms that confined themselves to supplying this market missed all of the growth that the industry was to enjoy, and eventually succumbed to obsolescence.

Some equipment makers made their peace with roll film, producing cameras under their own patents that would accommodate the Eastman product. Others sought to imitate directly, but incurred a plague of lawsuits for their trouble, as Eastman had built up a thicket of protective patents on products and processes that few could penetrate.

One of the most interesting reactions of the established producers was the introduction of products that aspired to improve the existing technology of dry plate photography. As in other industries, the old technology often finds ways of improving itself when faced with a serious challenger. In this case, a number of improvements came to the market: self-setting shutters, cameras that used sheets of celluloid in place of glass, small plate cameras.

One producer, anticipating the multiexposure capabilities of Edison roll film by a few years, introduced a plate camera featuring an internal "magazine" of some 20 plates. As one photograph was taken, the exposed plate would be mechanically moved out of the focal plane and stacked at the bottom of the camera chamber while a fresh plate was slotted into place. This camera must have been large and extremely heavy. Later versions could accommodate either glass plates or celluloid sheets.

Exhibit 1

Early developments in photography

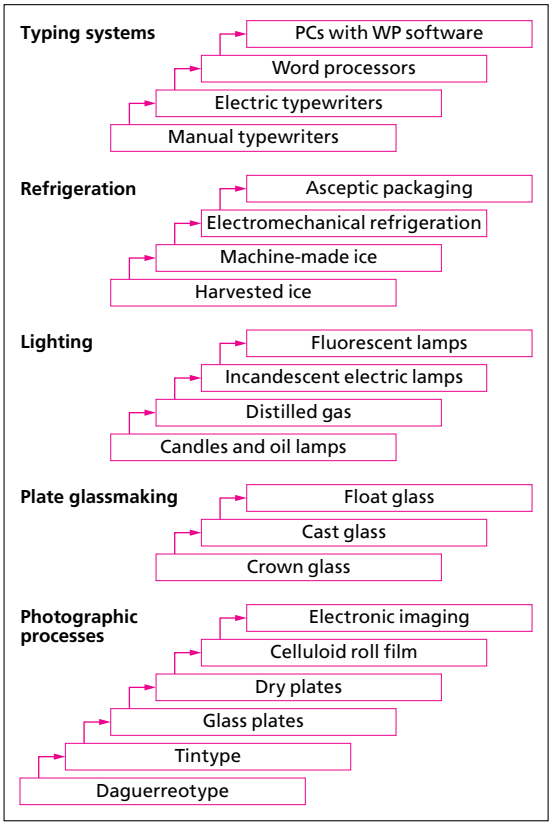
1839	Daguerreotype invented in France. Image produced on a silver-coated copper sheet
1855	Wet collodion on glass plate
	Ambryotype and tintype. Inexpensive variants on wet collodion technology enjoy some popularity
1880	Dry gelatin emulsion on glass plate
1885	Roll film, first paper backed, then celluloid

Lessons from the evolution of photography

The evolution of photography provides many good examples of the role that technological innovation plays in industries producing nonassembled products. In many respects, the patterns we find here are often shared with

Exhibit 2

Stages of innovation and change



assembled products, and managers can draw several important lessons from them.

Waves of innovation and change

Early developments in photography (Exhibit 1) illustrate how the underlying technology of an industry underwent waves of change in just four decades. The same can be seen in typewriting, plate glassmaking, refrigeration, and lighting *(see* Exhibit 2). These waves frequently share common characteristics:

Parallels with existing forms. Innovations are often suggested by existing forms. Consider the technological progression from daguerreotype to wet collodion to dry gelatin plate to celluloid film, which carried along many artifacts from old to new in terms of the underlying photochemical processes. The same is true of typewriters; important elements were carried forward in each wave of technological change. The QWERTY keyboard is the prime example, being a common feature of manual, electric, and now computer-based typing systems.

When mechanical icemakers went head to head with the New England ice harvesters, they chose to do so by producing ice blocks of the same dimensions, even though their technology gave them the freedom to create other sizes. Similarly, Edison sold his electric lighting system by deliberately aping as many of the forms of gas lighting as possible.

The emergence of a dominant design. Except for special applications, the roll format pioneered by Eastman rapidly took over as the dominant design in photographic film. Today, 35mm film in lightproof canisters is the accepted product form from Baltimore to Bangkok. Even Kodak's own attempt to introduce disk film has failed to make inroads.

This phenomenon is as much a result of the need for technical standards as anything else. Certainly a strong case could be made for 30mm or 45mm film, but the need to match film to a set of camera standards is far more

powerful. In this sense, 35mm film is to modern photography what the QWERTY keyboard is to typewriters and personal computers.

Outsiders as innovators. Particularly in assembled product industries, major innovations come from outsiders. Edison is a prime example, having no experience in the lighting industry prior to his first experiments with incandescent lamps. In the case of typing, IBM was an outsider when it began to trade in electric typewriters; moreover, none of the firms that made word processors and, later, personal computers had any standing in the typewriter industry.

The result of firms' reluctance to adopt successful new technologies has been a change of leadership at breakpoints in technology

The photography case offers the weakest evidence for this generalization, since Eastman was an important member of his industry at the time that he innovated celluloid roll film. However, the latest innovations in imaging are now coming from the electronics industry, which has nothing to do with chemical-based photography. In process-oriented industries such as glass, innovation often comes from the suppliers of process equipment rather than from the processors themselves.

A reluctance by established firms to adopt radical technology. In many cases, established firms have been slow to adopt radical technologies as they appeared. Some, like gas lighting companies, simply abandoned or were driven out of their markets. Others did try; some of the camera companies, for example, adapted their camera bodies to accommodate celluloid roll film. Among the manual typewriter firms that survived the 1930s and 1940s, most made some attempt to branch into electric machines, but none successfully caught the next wave of word processors and personal computers.

The result of this reluctance to adopt successful new technologies has been a change of leadership at breakpoints in technology. The torch is passed to new leaders as established firms fail to leap across technological discontinuities. Royal was eclipsed by IBM in the transition from manual to electric typewriters; the gas companies faded from the lighting business as the likes of Edison Electric and Westinghouse emerged; the leading dry plate makers faded away as Eastman's roll film gained market dominance.

The torch is passed to new leaders as established firms fail to leap across technological discontinuities

* *Author's note:* Kodak has recently released its own digital camera.

In the modern photographic industry, leadership may be poised to change once again. In 1989, Sony chairman Akio Morita called a press conference to unveil a new product: not a portable TV, not an improved microwave oven, but – of all things – a new camera. The remarkable thing about this camera was that it reproduced an image using electronic digital technology, a radical departure from the chemical tradition that began in France in 1839 and has dominated the industry ever since. With Sony's new system, the image can be viewed immediately on a television screen without any need for processing or developing.

The future of Sony's new image-producing technology is not clear. It may have only a few special applications; alternatively, it may become the way people take pictures in the future – which raises the question of how the massive industry based on photosensitive film will respond. The multibillion dollar business of Kodak, Fuji Film, dozens of camera makers, and tens of thousands of independent film processors around the world may be under threat. If electronic imaging becomes the wave of the future, which of these current producers has the competencies to make the leap to the new technology? *

Today, many believe that about 70 percent of manufacturing costs are dictated by product design; Eastman understood this intuitively

Linkage of product and process innovation

The linkages between product and process innovation are fundamental to the development of industries. They are expressed in a number of important ways:

A shift from product to process innovation. As product features are agreed to by producers and customers, and as markets expand, a shift takes place in the rate at which product and process innovations occur. Although the Eastman Company never stopped innovating in its products, moving on to faster, sharper, and then color films of great intricacy, there was a major shift early on from product to process innovation, just as there was in such other industries as ice and incandescent lamps. In general, this shift takes place earlier in nonassembled product industries. Photographic film certainly had all the hallmarks of a nonassembled product; however, as it entered the age of color, its complexity increased. It is something of a hybrid between the simplest of nonassembled products and more complex ones.

Dual focus on cost and quality. It was ever Eastman's strategy to consider cost, both in the design of the product and in the process that would manufacture it. We know, for instance, that he quickly replaced his original

Kodak camera with his No. 1 model because the former's shutter system was inherently costly to make. Today, many believe that about 70 percent of manufacturing costs are dictated by product design; Eastman understood this intuitively. His No. 1 camera featured a much simplified and more easily manufactured shutterworks.

Speculating as to why Eastman, operating out of provincial Rochester, became the global market leader instead of the Germans, who were the technical leaders in the sciences of optics, fine chemicals, and camera design, Reese V. Jenkins observes that "German products usually were very expensive and, therefore, produced in relatively small quantities. In contrast, George Eastman struck an enviable balance between quality and cost, focusing his financial and human resources on an international mass market and large-scale production." Some may see parallels with the mass-production/good-quality auto industry that prevailed in the United States from Henry Ford's day until the 1970s as against the low-volume/high-quality auto industry of Europe in the same period.

The expense of introducing process innovation. As an industry becomes more stable, greater reliance is placed on the use of specialized and expensive equipment. Innovations that require a production system to be altered are very expensive. This is a cruel irony for decision makers: process innovations hold out the promise (but not the guarantee) of truly major productivity gains, but at staggering cost.

Eastman faced this difficulty when Kodak shifted from using relatively inexpensive glass tables to manufacture photographic film by the batch method, to making the tremendous outlays necessary to implement continuous film production. Although costs were sure to be high, there was no certainty of outcome.

The importance of systems

Systems play an important role in achieving large-scale success in an emerging industry. Edison's system of incandescent lighting required the simultaneous development of lamps, wiring, sockets, generators, and so forth; ice harvesters similarly created a system for cutting, storing, and distributing ice both locally and to distant ports; photography *for everyone* required a simple camera and no-fuss processing, with both at a low cost. In the modern PC field, network system externalities – links with phones and fax machines, and even touch-typing skills – have proven to be vital. The development of such systems by industry pioneers undoubtedly creates barriers to aspiring competitors.

To a greater or lesser degree, innovations either enhance or destroy competencies that a firm already possesses

COURTESY OF EASTMAN KODAK COMPANY

George Eastman (left) and Thomas Edison examine a motion picture camera, 1928

The importance of competency

One way to appreciate the dimensions of the challenge that traditional firms may face – be they typewriter makers, ice harvesters, gas companies, or automakers – is to consider innovations in terms of their relationship to existing business and technical capabilities. To a greater or lesser degree, innovations either enhance or destroy competencies that a firm already possesses.

In photography, Eastman's roll film innovation involved some elements that enhanced the competency of established firms of that time (coating a transparent material with a photochemical emulsion), and some that were truly new and competency destroying (casting and cutting strips of celluloid that were uniformly thin and free from dust and air bubbles). Eastman's talent for devising and improving automated processes for coating dry plates and photographic paper served him well in developing the competencies he needed to make a success of mass production of roll film. His competitors in the dry gelatin plate business were equally girded with coating capabilities, but the business of casting celluloid film was entirely outside their experience and may have been the reason why so few of them bridged the discontinuity to roll film.

Similarly, General Electric moved easily from manufacturing incandescent lamps to making vacuum tubes for radios and televisions, but did not so easily bridge the gap from tubes to transistors; Kodak successfully navigated from photographic movie film to videotape; Sylvania moved from incandescent lamps to fluorescents. In each case, the innovations were competency enhancing. The sway of existing skills and attitudes is so great that J. Herbert Hollomon once commented that it was only when he built a

new factory in a new place with entirely new people that General Electric finally managed to produce transistors.

Eastman's competency in film production served him well as applications presented themselves. When Thomas Edison asked Eastman to produce a special film for the newly invented motion picture camera, Eastman already had the competencies needed to develop it: he had merely to strengthen and lengthen his strips of film and add holes to engage the movie camera's sprocket.

The importance of competency is illustrated equally well in the transition that took place between mechanical typewriters (manual and electric) and word processors. Nothing in the skills bank of Royal, Remington, Underwood, and the other established typewriter firms prepared them for the innovation of word processing, which operated without carriages, type bars, ink ribbons, and the other paraphernalia of the traditional industry. Competency in these areas in no way served the established firms in making the transition to word processing. The gas-illuminating companies were similarly confounded by their lack of competencies in electricity and electric lampmaking when that technology challenged their hold on the market.

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As a general rule, competency-*enhancing* innovations come equally from established firms and from outsiders. Competency-*destroying* innovations, however, nearly always come from outsiders.

The need to build new competencies in anticipation of future developments is an important element of long-term business success. George Eastman appears to have been one of the successful innovators who recognized this requirement. His firm had no competency in color film when its early precursors began to appear in European laboratories, but he recognized the importance of building it.

The advent of color photography in the first decade of the twentieth century was, like most radical innovations, pioneered by a firm outside the circle of leadership: Lumière Brothers. Eastman was acutely aware of the threat that their Autochrome process (1904) posed to his firm, even though it did not enjoy commercial success when it was marketed in 1907. He actively encouraged a number of independent efforts to develop the technology and had a trusted associate monitor the pace of progress by competing, mostly German, firms.

All his early attempts at color photography failed, and these failures spurred him to institutionalize R&D in the Eastman Kodak Research Laboratory. Eventually, in the late 1920s, his company did develop the capability to produce color film. Very likely the aging George Eastman, whose long experience had taught him the necessity of bridging the discontinuities of technological change, saw color film as critical to his company's continued leadership in the industry.

The idea of competency is critical to the survival of all firms as they encounter incremental and discontinuous technological change. As we have seen, it took just four decades for the whole of the photographic industry to be transformed. In the process, many previously successful companies disappeared. In an era of far more rapid and radical technological change, it remains to be seen how today's businesses will fare. Q