
Surviving Radical Technological Change through Dynamic Capability: Evidence from the Typesetter Industry

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Recent work in the field of management has focused on 'dynamic capability', the ability of a firm to develop new capabilities in response to shifts in its external environment, as a significant source of competitive advantage. This paper enhances our understanding of dynamic technical capability. While most established firms have difficulty adapting when confronted with radical, competence-destroying technological change, Mergenthaler Linotype, a firm founded in 1886, has survived three such revolutions and led the market in 1990. An examination of the history of this firm in contrast to other incumbents from the same era highlights two key contributors to dynamic technical capability: external integrative capability and geographically distributed research sites. External integrative capability comprises two elements: internal investments that develop absorptive capacity and an external communication infrastructure to facilitate the transmission of external knowledge. In combination, these elements enable the firm successfully to identify and integrate knowledge outside its boundaries. Geographically distributed research sites facilitate the development of new technical capability in three ways. First, competition among research sites spurs innovation. Second, multiple locations help to overcome organizational inertia by allowing for the development of different generations of technology in different locations. Finally, multiple locations provide a source of variation, enabling the firm to leverage differences in local environments.

1. Introduction

Firms often face their greatest challenges during dynamic periods of industry transition when the resources and capabilities that served to create

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competitive advantage in an earlier era can lose their value. During these periods, 'dynamic capability . . . the capacity of a firm to renew, augment and adapt its core competencies over time', becomes increasingly important (Teece *et al.*, 1992, p. 18). Dynamic technical capability appears to be particularly difficult for established firms to develop, with numerous examples of new entrants displacing established firms in industries transformed by new technology. For instance, the advent of electronic calculators, diesel-electric locomotives, jet engines and solid state semiconductors each enabled new entrants to overthrow entrenched competitors (Cooper and Schendel, 1976; Majumdar, 1984; Foster, 1986).

Drawing upon a detailed history of technological and competitive change in the global typesetter industry from 1886 to 1990,¹ this paper examines what factors make certain incumbents systematically better than others at adapting to radical technological change—in other words, what differentiates those firms with dynamic capability. While three firms, Mergenthaler Linotype, Intertype and Monotype, were extremely successful for over 50 years during the original generation of typesetter technology, only Mergenthaler was able to both survive and prosper in the face of three subsequent generations of radical, competence-destroying technological change. Mergenthaler Linotype was the market leader in 1900 when typesetters were mechanical 'hot metal' machines, and in 1990 Linotype-Hell, the successor to the original firm, was still the market leader in a market where a 'typesetter' had become a sophisticated computer that output high resolution digital color text and graphics.

A large body of research has examined the relative performance of incumbents versus new entrants in the face of radical, competence-destroying technological change. This work identifies three broad reasons incumbents might fail to develop a leading position in a new generation of technology: (i)

¹ Data for this study were gathered during an intensive 14-month field-based study of the typesetter industry conducted from the fall of 1993 through the winter of 1995. Secondary data came from a number of sources including technical journals, industry trade journals, consultant reports, government studies and company publications. The most useful sources were the *Seybold Report*, an industry trade journal dating back to 1971 that tracks and evaluates every new product in the industry, and complete sets of historical annual reports for Mergenthaler Linotype, Intertype and Monotype. Visits to company archives yielded internal company newsletters, internal memos, organization charts and business plans, helping to reconstruct the history of the firms. Finally, a number of retired employees had saved materials such as organization charts and memos and made them available.

This information was supplemented with a combination of over 50 in-person and phone interviews with industry experts and key individuals in the Mergenthaler, Intertype and Monotype organizations. Mergenthaler was examined in the most depth, with the list of interviewees including individuals (i) from multiple levels of the organization, (ii) from multiple functional areas, (iii) from all three geographical locations and (iv) across all four generations of technology. Interviews lasted from 2 h to 2 days and were mostly in-person. An open-ended questionnaire was sent to interviewees before the interview, and discussions were structured around the questionnaire.

they may fail to invest in the technology, (ii) even if they invest, they may have organizational difficulty developing new technical capability, and (iii) even if they invest and develop technologically competitive products, they may not possess the requisite complementary assets necessary to exploit their innovation in the commercial market.

Economic theory, building on work by Arrow (1962), suggests that when an innovation is incremental in an economic sense (i.e. it competes with the existing technology), then incumbent monopolists have a greater incentive than new entrants to invest. Similarly, if the innovation is radical (it replaces the existing technology) then new entrants have a greater incentive to invest (Gilbert and Newberry, 1982; Reinganum, 1983). An alternative explanation for incumbent lack of investment is put forth by Christensen and Bower (1996). They propose that when an innovation is 'sustaining', in that it meets the needs of existing customers, then incumbents will invest in order to satisfy their customer base. If, however, the innovation is 'disrupting', meaning that it does not address the needs of current customers, but instead is targeted at a different customer segment, then incumbents will fail to invest since their resource allocation mechanisms focus on existing customers.

When incumbents do invest in radical, competence-destroying technology, they are often at a disadvantage relative to new entrants in developing new technical capability. Organizational structures, architectures, routines and procedures that have evolved during periods of incremental technological change are difficult to displace (Burns and Stalker, 1961; Arrow, 1974; Nelson and Winter, 1982, Henderson and Clark, 1990). As a result, when faced with competence-destroying technological change, the technical performance of products developed by incumbents is often inferior to that of new entrant products (Cooper and Schendel, 1976; Majumdar, 1982; Tushman and Anderson, 1986; Henderson and Clark, 1990).

Even if incumbents invest and develop technologically competitive products, if new entrants possess the specialized complementary assets necessary to exploit the innovation, then incumbents may still fail in the marketplace (Teece, 1986). This result is most likely in cases where an innovation has high transience, meaning that linkages to existing customers are no longer valuable (Abernathy and Clark, 1985). In this case the sales and service networks of incumbents lose their value, and new entrants with linkages to new customers may have an advantage. Empirical work in the field of medical diagnostic imaging has demonstrated the importance of these linkages (Mitchell, 1992). Similarly, empirical work has shown that when the 'value network . . . the system of producers and markets serving the ultimate user of products or services to which a given innovation contributes' changes,

incumbents are more likely to fail, whereas when it remains constant, they are more likely to survive (Rosenbloom and Christensen, 1994, p. 657).

While this stream of research clearly documents the potential disadvantage faced by incumbents relative to new entrants, it does not address systematic differences among incumbents. Although incumbents on average may fail relative to new entrants, what explains the differential success of certain incumbents? While limited in scope, the existing empirical work on dynamic capability provides some insight. Empirical research in the pharmaceutical industry (Henderson, 1994) as well as the auto and mainframe computer industries (Iansiti and Clark, 1994) suggests that integrative capability is an important element of dynamic capability. Henderson notes the importance of both internal integration across disciplinary boundaries and external integration across firm boundaries when pharmaceutical firms were attempting to move from traditional 'random' to modern 'rational' modes of drug discovery. Internal integration includes mechanisms such as cross-functional teams, and external integration involves a focus on publication in order for scientists to be integrated in the larger scientific community. Similarly, Iansiti and Clark (1994) find that internal integration (cross-functional teams), customer integration and technology integration (a system focus in development) improved a firm's dynamic performance. This paper extends this work by further exploring the role of integrative capability as well as examining other possible factors that might contribute to dynamic capability.

Two elements of dynamic capability emerge from this study. First, consistent with prior work, the ability to identify and integrate knowledge outside the boundaries of the firm proved crucial to the development of new technical capability. I call this ability 'external integrative capability'. External integrative capability comprises two elements: (i) internal R&D investments that develop 'absorptive capacity' (Cohen and Levinthal, 1990); and (ii) a strong external communication infrastructure to facilitate the transmission of external knowledge. This infrastructure comprises both informal mechanisms such as know-how trading (von Hippel, 1987; Schrader, 1990) and more formal mechanisms such as strategic alliances or long-term supplier relationships. Each of these elements of external integrative capability cumulates over time and therefore must be developed during periods of incremental change, not simply acquired during periods of transition.

Second, the use of geographically distributed R&D locations can help firms to develop new technical capability. By encouraging competition as well as cooperation among engineers, multiple R&D sites spur innovation. When technological generations overlap, then different generations can be

developed in different locations in order to avoid the difficulties associated with transforming an established organization. Finally, different locations are a source of variety and allow the firm to tap into different networks of local expertise.

The paper begins by describing the history of technological change in the typesetter industry. Given the high level of technological turbulence in the industry, it next compares descriptive data on the performance of Mergenthaler Linotype and the two other leaders in the original generation, Intertype and Monotype. The following section describes the history of each firm's attempts to adapt to multiple changes in technology, and the last two sections compare and contrast the three firms in order to understand why Mergenthaler was so successful in comparison to the other two. The importance of external integrative capability and geographically distributed R&D are highlighted.

2. Technological Change in the Typesetter Industry

Typesetting is the process of arranging text (and now images) as input to the printing process. It originated with the invention of moveable type by Gutenberg in the 1400s. With moveable type, a skilled craftsman took individual pieces of type from two cases—an upper case and a lower case—and placed the letters in the correct order into a frame. Once a complete page was set in the frame, it was secured, 'inked' and a sheet of paper was pressed against the raised letters in order to produce a printed page.

Prior to Gutenberg's invention of moveable type, printed material was available to only a small, élite portion of the population. Moveable type, however, enabled significantly larger quantities of printed material to be produced and distributed, and the demand for printed material grew substantially. Newspapers and commercial printers expressed a need to speed up the process of typesetting in order to meet this increase in demand. While several inventors over the following years confronted this challenge, their success was limited.

Most inventors attempted to automate the existing process of setting type by hand. Inventors came up with very creative ways to replace the person who arranged the individual pieces of type. Perhaps the most notorious of these inventions was the Paige typesetter, a machine financed by Mark Twain. Unfortunately, the investment sent Twain into bankruptcy. Twain was not the only one to lose his fortune in the search for a mechanical typesetter. Over 170 different prototype inventions attempted to automate the process of

TABLE 1. Comparison of Typesetter Technological Generations

Generation (year introduced)	Controlling machine logic	Escapement	Font format	Character output	Architectural innovation?	New skills
Hot metal typesetter (1886)	mechanical	mechanical	metal matrix	hot metal	NA	NA
Analog phototypesetter (1949)	electro-mechanical	mechanical	film	xenon flash	yes	90%
Digital CRT phototypesetter (1965)	electronic/software; programmable minicomputer	mechanical/electronic	digital start/stop pattern	CRT strokes	yes	70%
Laser imagesetter (1976)	electronic/software; micro-processor	electronic	proprietary digital outline	laser raster strokes	yes	50%

typesetting before the invention of the Linotype machine by Ottmar Mergenthaler (Legros and Grant, 1916).

Ottmar Mergenthaler took a fundamentally different approach. Instead of imitating the job of the hand typesetter, his machine reconfigured the entire process. The Linotype machine did not arrange precast pieces of type; it arranged molds of letters called matrices in a row and then cast a 'line of type' by injecting molten lead into the row of matrices. The commercialization of Mergenthaler's invention sparked the emergence of the typesetter industry. Called hot metal typesetters, variants on Mergenthaler's basic design dominated the typesetter industry for the first half of the 20th century. The industry has since been transformed by three generations of radical technological change. Each of these new generations destroyed the value of the technological competence that firms had been built up in the prior generation (see Table 1).

While hot metal typesetters were large, heavy, noisy mechanical machines, the next generation of machines, analog phototypesetters, were smaller, quieter, and the basic machine logic became electro-mechanical. In addition, the method of storing fonts went from an impression on a piece of metal to an analog image on film, with text output onto film. As an operator input text at a keyboard, characters were selected from a spinning disk, with a strobe light going off just as the correct character passed in front of the flash tube. The image of the letter passed through a series of lenses and was then exposed onto film. In the following generation, digital CRT phototypesetters,

most of the moving parts of the typesetter were eliminated since machine logic was now controlled through electronics and software. Characters were magnetically stored as a digital series of start/stop points, and a vertical CRT scan was used to 'write' the character's image onto film. Finally, in the laser imagesetter generation, machines began to output both text and images. Rather than write a letter at a time, a raster stroke that horizontally wrote out a portion of an entire line was used. Lasers also replaced CRTs as the output mechanism.

Each of these new generations of technology was competence-destroying from the standpoint of both the technical skills required to develop the product, and the architectural knowledge (Henderson and Clark, 1990) of the development team. Based on an examination of the product development records of a subset of firms, the percentage of new skills was calculated for each generation (see Table 1). For instance, while 100% of the development team for a hot metal machine were mechanical engineers, only 10% were mechanical engineers in an average analog phototypesetter development team, so 'new skills' was 90%. Each generation of technology also destroyed architectural knowledge. Components changed significantly, with, for instance, the method of storing a character changing from an impression in a piece of metal to an analog image on film to a series of electronically stored start/stop points to an electronically stored mathematical algorithm describing the outline of a character. The nature of component interfaces also shifted dramatically, with machine logic moving from mechanical to electro-mechanical to electronic to software-based.

3. A Comparison of Innovative Performance

Success in the Hot Metal Era

Figure 1 shows the number of firms in the industry from 1872 to 1990. After a great deal of entry and a shakeout, three firms, Mergenthaler, Intertype and Monotype, emerged as successful during the hot metal era.² By 1916 Mergenthaler Linotype had about 60% of the world market, Intertype 25% and Monotype 10%.

As discussed above, Mergenthaler Linotype entered the industry in 1886 with a fundamentally different type of machine. The first production model of the machine came out in 1890 and sales took off quickly, sparking the growth of the entire industry (see Figure 2). By 1895 Mergenthaler claimed

² This pattern of entry and exit is similar to that found by Utterback (1994) in a number of industries.

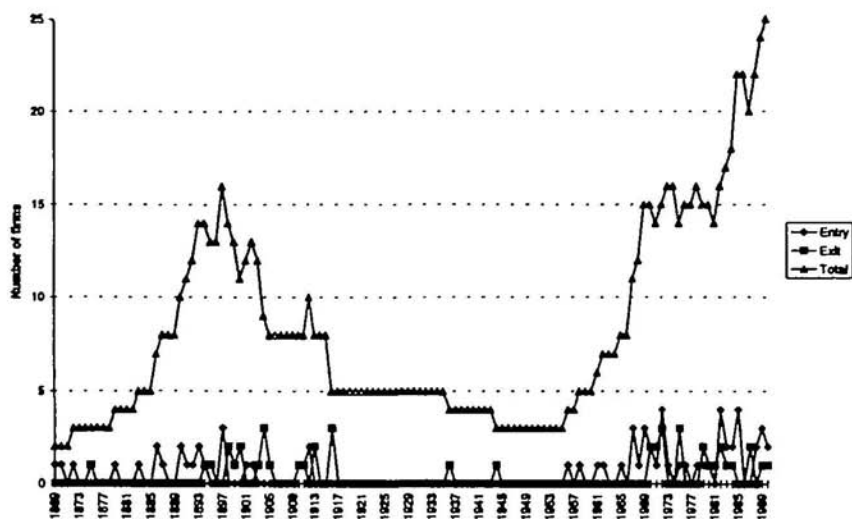


FIGURE 1. Number of firms in the typesetter industry, 1869–1990.

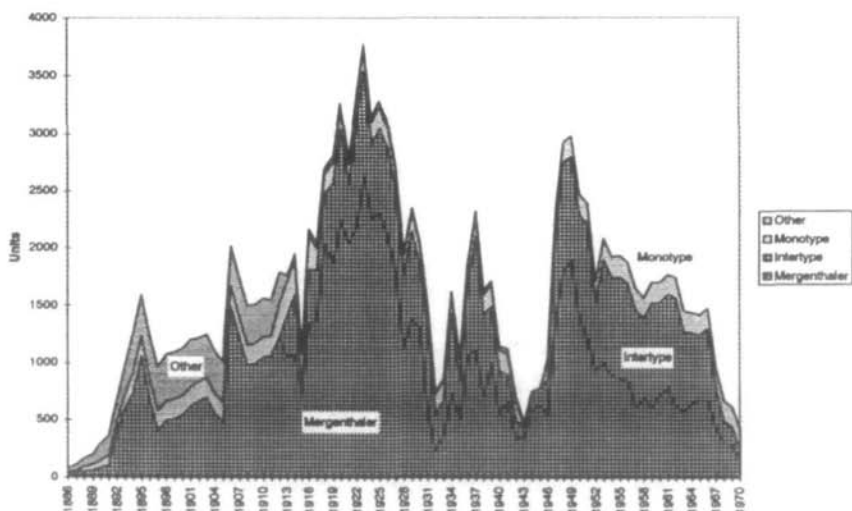


FIGURE 2. Typesetter industry hot metal unit sales by firm, 1886–1970.

in its annual report: 'The Linotype is now recognized as the leading machine of the world in its class . . . numerous machines, designed as competitors, have been abandoned by their promoters, and the only remaining machines in the US . . . are steadily losing ground.'

While most competitors were indeed losing ground, one firm, Monotype, was gaining a foothold in a specialized niche. Introduced in 1890, the Monotype machine cast hot metal into molds of letters, but as the name implies, only a single character was cast at a time. The architecture of the Monotype machine was thus totally different from the Mergenthaler machine. The machine had two separate units, a keyboard and a caster, with a 31-channel paper tape interface. The primary advantage of the machine was that it had 225 different characters accessible at once, whereas the original Mergenthaler machine only had 80. The Monotype machine was therefore successful with a small, specialized market segment that had complex typesetting applications (e.g. mathematical formulae, tabular materials and foreign languages).

The other successful entrant in the hot metal era was Intertype, a Mergenthaler spin-off started in 1911 when some of Mergenthaler's key hot metal patents expired. The Intertype machine was based on exactly the same architecture as the Mergenthaler machine, and it could even use the same matrices. As seen in Figure 2, after a slow start, Intertype sales eventually matched those of Mergenthaler.

Performance in Competence-destroying Generations

After more than 60 years of success in hot metal technology, one would expect that three subsequent generations of competence-destroying technological change might overturn the position of these three incumbents. As seen in Figure 1, there was a great deal of entry starting in 1956, when new technology invaded the industry. While both Intertype and Monotype suffered significantly at the hands of new entrants, Mergenthaler managed not only to survive, but to prosper. Mergenthaler's cumulative share³ of the analog phototypesetter generation was only 8%, but it recovered to capture 35% of the CRT and 30% of the laser generations (see Figure 3). While not comparable to the near-monopoly position the firm held in the hot metal generation, with shares of 35% and 30% it was still leading the industry. In contrast, Intertype's share dropped to 2% in both the analog phototypesetter and CRT generations, followed by a withdrawal from the industry. Monotype captured only 1% of the analog phototypesetter generation and totally missed the CRT generation. With assistance from the British government the firm recovered to capture about 5% of the cumulative laser imagesetter generation

³ Calculated based on all machines of that generation sold through 1990.

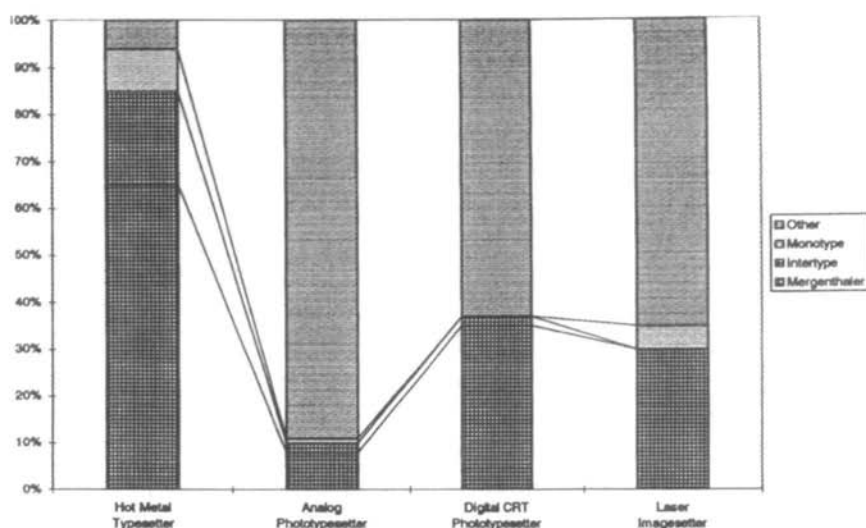


FIGURE 3. Typesetter unit market share by generation.

TABLE 2. Year of Entry into New Technology for Hot Metal Incumbents versus New Entrants

Technological generation (year introduced)	Mergenthaler	Intertype	Monotype	New entrant average
Analog phototypesetter (1949)	1959	1949	1957	1967
Digital CRT phototypesetter (1965)	1967	1968	no entry	1973
Laser imagesetter (1976)	1980	no entry	1976	1984

(through 1990) although by the late 1980s the firm's annual share had declined to about 3% and was continuing to fall.

One might suspect that late entry was responsible for the poor performance of Intertype and Monotype. An examination of entry dates, however, reveals that the three hot metal incumbents actually entered each new generation of technology earlier than the average new entrant, and Mergenthaler entered slightly later than Intertype or Monotype. Entry timing therefore does not appear to have played a significant role in explaining performance.

Despite the drastic decrease in market share of the new technologies, it is interesting to note that Intertype still did not exit the industry until 1984, Monotype managed to survive long enough to be somewhat revitalized by government intervention, and Mergenthaler survived relatively poor

performance in the first shift and was able to recover in the second and third shifts. Why were these firms able to hold on for so long despite a great deal of new entry? There are two main reasons. First, substitution for hot metal technology was extremely slow, with 50% of annual industry unit sales still hot metal machines as of 1968. Labor union opposition to new technology slowed adoption in developed nations, and in third world countries a lack of knowledge about electronics made buyers more comfortable with the well-known mechanical machines. As a result, each firm was able to continue earning profits from the sale and maintenance of hot metal machines despite a failure to effectively develop new technology. In fact, manufacturing of Monotype casters continued until 1987. Second, these firms were protected from competition by specialized complementary assets, in particular strong sales/service networks and large font libraries (Tripsas, 1997). All three hot metal incumbents had developed strong international sales/service forces, with contacts at key customers such as newspapers, typographers and commercial printers.⁴ Technological change had low transience in that these customers remained important in succeeding generations. In addition, all three hot metal incumbents invested in developing large libraries of fonts. A wide selection of fonts was a critical buyer purchase criterion, and without one, firms found entry difficult. Both the sales/service network and font library were difficult for new entrants to acquire or replicate, thus providing incumbents a buffer from competition.

Since all three hot metal incumbents benefited from these factors, they still fail to explain the differential performance of Mergenthaler relative to Intertype and Monotype. The next section therefore examines how each firm approached developing new technology.

4. The Evolution of Dynamic Capability

Two themes emerge from comparing the firms' histories. First, since radical technological advances often originate outside the boundaries of the firm—at universities, competitors, suppliers or users (von Hippel, 1988) or in other industries—the ability to identify and integrate external knowledge is crucial to successful technological transitions. I call this ability 'external integrative capability'. It includes two elements: internal investments in new technology in order to develop absorptive capacity, and an external communication infrastructure to facilitate the transmission of knowledge.

⁴ A fascinating description of a Linotype salesman's travels through the third world in the early 1900s can be found in the autobiographical book *Merchants of Alphabets*.

Cohen and Levinthal (1990, p. 28) use the term 'absorptive capacity' to describe a firm's 'ability to recognize the value of new information, assimilate it, and apply it', and argue that 'prior related knowledge confers absorptive capacity'. In other words, firms that have invested in internal R&D related to a particular technological domain will be more successful at absorbing related external information. Individuals working in a given area are better able to judge and internalize familiar information as well as communicate with external experts. Internal R&D was found to be the most important part of a technology acquisition strategy in a study of Japanese, US and Swedish firms (Granstrand, 1992).

An external communication infrastructure includes both informal relationships such as know-how trading with other technical experts, and more formal mechanisms with levels of commitment ranging from technology scanning to hiring external consultants to forging alliances with other firms. This infrastructure must be developed over time during periods of incremental technological change in order to be effective during radical periods of transition.

The second theme concerns the importance of geographically distributed research locations. Distributed R&D encouraged innovation due competition among R&D sites. Multiple sites also helped to overcome organizational inertia by allowing different generations of technology to be developed at different locations. Finally, multiple locations enabled access to differing local expertise. I next describe the evolution of each firm's technological capability, with a focus on exploring these two themes.

The Mergenthaler Linotype Company

Mergenthaler had strong development capability in hot metal technology as evidenced by an ongoing series of incremental improvements made to the machine after its initial introduction in 1886. The 1899 annual report stated, 'Constant attention has been given to the improvement of the standard machine. . . . It will be the continued aim to keep the Linotype in advance of all other machines.' Table 3 lists some of the incremental improvements made by Mergenthaler between 1886 and 1942. For instance, users wanted access to more than one typeface at a time, so machines that had multiple magazines of matrices were designed (e.g. models 2, 8 and 9). Other innovations such as the electric metal pot (1915) and the Micro-therm pot (1939) improved the heating of the molten lead.

This internal investment created absorptive capacity, an ability to value and effectively integrate technological developments occurring outside the

TABLE 3. Incremental Improvements to the Mergenthaler Hot Metal Linotype

Year	Innovation	Description
1886	Blower Linotype	original machine
1890	Square Base Model 1	power driven keyboard; inclined magazine
1892	Model 1	massive square base replaced with star base
1897	wide-measure	maximum width increased from 30 to 42 ems
1898	two-letter matrix	matrices had two rather than one character punched in them
1901	individual motors	simplified driving of machine and took less space
1902	four-mold disk	decreased need to frequently change molds
1903	Model 2	two-magazine machine
1903	Model 3	allowed point sizes larger than 11 pt
1906	Model 4	quick-change double magazines
1906	Model 5	separate escapement mechanism saved space
1909	water-cooled mold disk	speeded up cooling of slugs after casting
1911	Model 8	three-magazine machine
1911	Model 9	four-magazine machine
1914	Model 14	auxiliary magazine
1915	electric metal pot	substituted for heating metal by gas
1918	Model 20	set display typefaces
1921	Models 21 and 22	permitted wider faces
1924	Models 25 and 26	eliminated parts for magazine escapement
1929	swinging keyboard	increased accessibility of keyboard parts
1931	mechanical thermostat	simplified control of heat for electric pot
1931	2-in-1 Linotypes	allowed shift from text to display range
1934	precision knife block	improved trimming of slugs
1935	wide-standard magazine	allowed use of wider typefaces
1936	Blue Streak Linotypes	numerous improvements for ease of use
1939	Micro-therm pot	improved heat distribution
1941	Models 35 and 36	improved mixing of small and large faces
1942	auto-ejector	improved ejection of slug after cooling

boundaries of the firm. In fact, much of the incremental innovation during this period originated with external technology. A number of factors were responsible for this external orientation. First, the firm was faced early on with the need to replace its key internal developer—disputes between Ottmar Mergenthaler and the firm's financiers resulted in an early departure of the inventor in 1888. This situation forced the firm to look outside for developers and to integrate them into the organization.

Second, Mergenthaler acquired a number of firms in order to limit competition. The developers of competitive machines were then integrated into the Mergenthaler organization. For instance, in 1895 Roger's Typograph was acquired, and John Rogers became a lead engineer for Mergenthaler. Other acquisitions included the Burr-Empire Co. in 1904 and Monoline in

1905. Technological advances present in these companies' machines were incorporated in the Linotype machine.

Finally, Intertype's entry into the industry in 1911, while a competitive concern for Mergenthaler, was helpful in terms of establishing an external communication infrastructure. Given the technical similarity between the two machines, an informal know-how trading network (von Hippel, 1987; Schrader, 1990) emerged among the service personnel at the two firms as they helped each other to repair troublesome machines. New ideas were then fed back to the development organization. This informal communication infrastructure complemented internal technology investments in order to create strong external integrative capability. Mergenthaler thus had a strong infrastructure in place to support the examination and incorporation of external technology.

The foundation of Mergenthaler's international strength was also laid in the hot metal era. The original linotype technology was licensed to a British firm in 1889 and to a German firm in 1896. In 1909 the US company purchased large interests in both, giving it a strong international presence very early on. The foreign subsidiaries did their own manufacturing and also developed their own incremental improvements to the linotype machine. While there was some sharing of product innovations between the US and UK organizations, there was almost no sharing with Germany. The culture of the firm was therefore never one of a central research lab transferring technology to satellite labs. Each country subsidiary had its own independent development organization. This independence played a major role later on.

Given the many years of experience Mergenthaler had in hot metal development, one would expect the transition to a radically different technology, phototypesetting, to be difficult, and it was. The firm had become very efficient at hot metal product development, with strong routines and procedures fine tuned to work within the context of the hot metal technological regime. Analog phototypesetter development required breaking those routines.

Mergenthaler began work on a phototypesetter in about 1948. Since individual inventors had been doing research in phototypesetting throughout the hot metal era, engineers at Mergenthaler were aware of the technology from various trade shows and publications. The initial project was led by hot metal engineers, and the phototypesetter was based on the same architecture as the hot metal machine. It used recirculating matrices which had a painted image of a character on the matrix where the impression of the character would have been etched on a hot metal matrix. When a line of matrices had been composed from the keyboard, it was moved over to the modified 'casting

unit' where a picture of the completed line was taken. The machine, called the Linofilm, was exhibited at a trade show in Chicago in 1950. An internal corporate newsletter dated October of that year stated:

The Comet, the ML Quadder [hot metal developments] and the Linofilm were ready in time for the International Graphic Arts Exposition in Chicago in September. . . . Linotype with its three research developments, was widely heralded as the hit of the show.

Despite this apparent enthusiasm, Mergenthaler management decided not to continue development of the machine based on extremely negative input from the sales organization. As an internal memo from the vice-president of sales to the sales force dated October, 1952 states:

Lately we have been receiving a number of requests for information regarding our Linofilm machine. . . . We developed this machine and showed it at Chicago to demonstrate that we had available a machine that would do anything that was presently available on the market. To be very specific, this machine can do what the Intertype Fotosetter can do. However, we . . . do not consider this machine the answer to the photo-composition problem. . . . Anyone who purchases a photo-composing machine should reasonably look for some savings or greater facilities than are now offered, and neither the Linofilm nor the Fotosetter offers these advantages. . . . Just tell your customers that we are not yet ready to put on the market a machine for photocomposition. Do not write in and ask us when we think our photo-composing machine will be ready—we actually don't know.

The influence of sales in this decision was invaluable and saved Mergenthaler from focusing on an obsolete mechanical architecture when new entrants to the industry were developing electro-mechanical machines. The first analog phototypesetter to be commercialized by Mergenthaler, also called the Linofilm, was not shipped until 1959, and it was an electro-mechanical machine. The earlier effort appeared to have had some influence in that the need for external expertise was clearly recognized. The new Linofilm development team, formed in 1953, comprised almost all newly hired engineers including a number of electrical engineers, and an external consultant, a professor from Columbia, designed the critical optical subsystem. A new director of the Research and Engineering Division had been appointed in 1953, and he had strong ties to Columbia University. As a result, other links with Columbia professors were also encouraged.

The arrival of a new CEO, Jack Keller, in 1956 served to further emphasize the focus on acquiring external technology. Keller immediately cut back on hot metal R&D and clearly focused the firm on phototypesetter development.

Engineers were encouraged to attend trade shows and avidly examine competitor's products as well as meet with suppliers of potential new technologies. As one Mergenthaler development engineer from this era stated in a 1993 interview: 'We didn't invent any technology. We observed existing technology and said, "How could we use that?"'

The Linofilm was not particularly successful. Part of the problem may have been that the phototypesetter developers were still immersed in the hot metal culture, with members of the project team still part of the same engineering organization as the hot metal developers. In fact, hot metal development was going on concurrently in the same building. The firm was, however, gaining expertise from outside sources, and at the same time building its infrastructure in order to continue accessing external knowledge. Follow-on development efforts, the Linofilm Quick in 1964 and the Linofilm Superquick in 1968, were much more successful. The 'VIP', a machine shipped in 1971, was the most successful of the subsequent developments. This machine was the first to incorporate a computer, and in the spirit of external technology integration that portion of the machine was not developed in-house, but was contracted out. By the time the VIP was developed, however, 13 new entrants had entered the typesetter market, and Mergenthaler had lost significant market share in the new generation of technology.

Another important development during this generation was the rekindling of the German R&D organization. After World War II, development work in the UK and Germany had slowed. The German firm had to rebuild its manufacturing facility for hot metal machines, and incremental hot metal development in both countries was minimal. Neither subsidiary invested in new product development, so they depended upon the US firm for phototypesetter products. In about 1967, however, the German organization felt that there was an opportunity to develop a phototypesetter targeted at the European market. Berthold, an old line German type foundry had entered the typesetter market in 1967 and was experiencing a great deal of success. A new German R&D group was therefore formed in order to develop a competing product. The Linofilm Europa was shipped in 1970 and the Linotronic in 1976. These products had moderate success in the German market, but more importantly they formed a foundation for further German development efforts.

A sense of competition also began to emerge between the US and German development organizations. The Americans clearly felt the German products were only appropriate for the German market. As one American development engineer stated:

The German products appealed only to Germanic countries and did not

have the broader appeal that the US-designed products had. Given their location, the Germans were not capable of understanding the needs of other users.

The Germans were determined to prove them wrong and demonstrate the viability of their products worldwide. They would succeed in doing so during the next generation of technology, the digital CRT typesetter.

With the practice of looking for external sources of technology clearly established in the analog phototypesetter generation, an alliance with CBS Labs to develop its first CRT machine was easily acceptable by the US Mergenthaler development organization. In addition, in the late 1940s Mergenthaler had done some preliminary research into using CRTs in typesetting, but had determined that the resolution was not fine enough for typography (Corrado, 1976). Although far removed, this prior related knowledge may have helped the firm decide to invest in the new technology via a collaboration with CBS in 1965.

This collaboration was in response to a Request for Proposal by the US Government Printing Office for an extremely high-speed typesetter machine that could interface with computers. The product developed by Mergenthaler and CBS, the Linotron 1010 was technically complex and overpriced, so only five units were ever sold. The project did, however, provide the opportunity to learn about CRT technology from CBS. Unfortunately, the amount of knowledge transferred was minimal. Mergenthaler had invested in developing the software component of the machine and had not directly invested in developing any CRT technology, leaving that portion of the project to CBS. As the Mergenthaler project head stated: 'There was very little CRT technology transferred. We focused on getting our part done and didn't really understand what CBS was doing.'

At the end of this project, Jack Keller felt that the firm still needed to go outside to acquire CRT expertise. Having tried to develop the initial phototypesetters in-house he felt that the firm could avoid many of the organizational difficulties encountered in transforming the existing organization by making an acquisition. Despite the 'failure' of the CBS alliance, Mergenthaler had absorbed enough knowledge to evaluate acquisition candidates with CRT technology, and in 1967, an innovative and successful British firm, K. S. Paul was acquired and renamed Linotype-Paul. Interestingly, each of the other hot metal incumbents, Monotype and Intertype, had considered acquiring K. S. Paul but had decided against it. Mergenthaler, with its limited experience in CRT technology was the only firm to recognize the potential of K. S. Paul's CRT machine.

K. S. Paul had developed a CRT machine which Mergenthaler sold as

the Linotron 505. This product was moderately successful, and its successor, the Linotron 202 was hugely successful. K. S. Paul had a strong external communication infrastructure, especially with suppliers and users, and continued to leverage those relationships. For instance Ronald McIntosh, one of the developers of the Linotron 505 machine, had an ongoing relationship with Arthur Phillips, the director of the Her Majesty's Stationery Office⁵ (the equivalent of the US Government Printing Office). While K. S. Paul continued to invest in external relationships, the US organization never developed expertise in CRT technology. Some linkages between the US and UK groups were developed for the Linotron 202, with the US organization contributing to the software used in the machine, but the US organization never acquired enough expertise to develop a CRT machine of its own. As a whole, however, Mergenthaler was successful in making the transition in that it learned enough about the technology to recognize its own inability and acquired a firm with the necessary skills.

With the acquisition of K. S. Paul in 1967, Mergenthaler now had three separate R&D groups.⁶ The US and German organizations were working on analog phototypesetters, and the UK organization was working on CRT phototypesetters. Just as the Germans and Americans had experienced some rivalry during the development of analog phototypesetters, the Germans and British experienced rivalry in the CRT generation. By 1976 when the Germans began shipment of the Linotronic, an analog phototypesetter, it was clear that the market was beginning to move towards CRT technology. Four percent of the total market was CRT machines and most major competitors had CRT machines under development. Rather than continue to have two of the three development organizations work on the 'old' analog phototypesetter technology, a decision was made to have the Germans begin work on a CRT machine.

Since all CRT development up until that point had taken place in the UK, an effort was made to transfer technology to the Germans. German engineers visited the UK on multiple occasions in the mid-1970s in order to learn about CRT technology. In about 1976, both the UK and German groups began development of new CRT machines. The German machine was to be a desktop model and target a slightly different market segment from the UK machine. The competition between the two development groups during this

⁵ When I interviewed Ronald McIntosh at his home in 1995, he was still in contact with Arthur Phillips despite the fact that they had both retired. In addition, in the acknowledgments to his 1980 book, *Handbook of Computer-aided Composition*, Phillips states, 'I have to thank Ronald McIntosh for many helpful discussions over some fourteen years on the operation of CRT phototypesetters.'

⁶ The original UK hot metal development group slowly closed down via retirements, and by 1967 was minimal. They remained a separate subsidiary from K. S. Paul and there was no attempt to integrate the two firms.

period was intense and resulted in two very successful products. The UK organization shipped the Linotron 202 in 1978, with more than 13 000 of these machines sold over its life. The German organization shipped the CRTronic in 1979, and over 15 000 of these machines were sold. As a basis for comparison, the VIP, Mergenthaler's most successful analog phototypesetter, sold only 3500 units.

The pace of change accelerated with each new generation of technology. It was 63 years between the first hot metal typesetter in 1886 and the first analog phototypesetter in 1949. Only 16 years later in 1965 the first CRT machine was shipped, and a mere 11 years later, in 1976, the first laser machine arrived. Mergenthaler's relatively recent prior experience in dealing with the shifts to analog phototypesetters and CRT phototypesetters clearly helped in making the transition to laser imagesetters.

Once more, rather than develop the first machine in-house, external expertise was brought in. Through contact with suppliers, Linotype-Paul became aware of an individual developing laser scanners for fax transmission. Since phototypesetter development in the US was winding down, the initial laser work was to take place there while the UK and German groups continued to make incremental CRT enhancements. So this individual was brought to the US, and development of a laser imagesetter began. The development group, which comprised both new-hires and some existing employees, was located in Connecticut, away from the main Mergenthaler facility. By assigning internal employees to work with the outside 'expert' a base of knowledge was built in the US organization. The result of this effort, the Omnitech 2000 was not particularly successful, but the group had both developed internal capability as well as some external relationships. Further US development moved to the main facility.

At the same time, laser development efforts also began in the UK and in Germany. Ongoing technology scanning in each of these locations continued to be strong, with the technical director of the British organization commenting in an interview (*British Printer*, 1982, p. 57): 'Every time a new product appears in these industries [computers and aerospace] we have to take a careful look at it.'

While there was some effort to coordinate efforts among the groups, there was also clear competition. This competition was intensified by a change in ownership. Allied Chemical Corporation acquired the Mergenthaler Linotype Company in 1979,⁷ and after an initial period of 'hands-off' management the

⁷ The Mergenthaler Linotype Company was a distinct corporation from 1890 through 1963. At that point, in an unrelated diversification, it acquired Electric Autolite and Mergenthaler's official corporate name was changed to Eltra Corporation, with the Mergenthaler Linotype Company an unincorporated

firm decided to consolidate the R&D groups in 1983 to eliminate duplication. The US organization had announced the Linotron 101 that year, but before volume shipments of this machine began, the US and UK development and manufacturing organizations were closed down. The motives for choosing to keep the German group over the other two are unclear. Interviews with individuals at all three locations indicate that the technical capabilities of the groups were comparable. One hypothesis, however, is that the strength of the German printing press sector accounted for the choice of Germany (Porter, 1990). With about 35% of world printing press production and 50.2% of world export production in 1985, Germany was clearly a leading force in the industry. By locating the development group near firms with printing press expertise, one could argue that developers had access to a stronger local network of experts.

Whatever the rationale, the consolidation did not immediately hurt Mergenthaler. Building on the work of the US and UK development teams, the German group was quite successful in developing a laser machine, with the Linotron 300, shipped in 1985, selling almost 13 000 units before it was discontinued in 1995. Successors to this machine helped Mergenthaler to obtain about a 30% share of the laser generation and as of 1990 the firm was strongly positioned as the market leader.

While the use of multiple development sites was considered unnecessary duplication in 1983, the need to access local expertise in the US caused the firm to alter its position. In the early 1990s it opened a small office in the US to take advantage of the regional software expertise in the Silicon Valley. Adobe Systems, the developer of Postscript,⁸ a dominant software standard used in typesetters, is located there, and German developers often spend significant amounts of time in the US office interacting with Adobe engineers.

Table 4 summarizes the activities and investments that form the basis for the judgment that, with the exception of the US organization in the CRT generation, Mergenthaler developed external integrative capability in each generation of technology. In addition, multiple development locations were utilized to the firm's advantage. In contrast, as described in the next two

division. Eltra Corporation was acquired by Allied Chemical Corporation (later renamed Allied Corporation) in 1979. In 1987, Allied sold the Linotype division to the Commerzbank AG in Germany, and later that year a public offering for Linotype AG was made on the German stock exchange. As of 1990, the firm had strong market and financial performance, and in that year Linotype AG acquired Hell Graphic Systems, a leader in digital screening technology, and the name of the firm became Linotype-Hell AG.

⁸ The advent of Postscript has had a significant impact on competition in the typesetter industry, resulting in overall decreased profitability for all firms in the industry. A wave of consolidation has occurred in the industry, with other top firms in the industry such as Compugraphic being acquired (by Agfa). Linotype-Hell's performance also suffered in the mid 1990s, and in October 1996 Linotype-Hell was acquired by Heidelberg Press, a German printing press company.

TABLE 4. Mergenthaler Linotype Product Development History

Generation	External integrative capability	
	Internal investments in knowledge (absorptive capacity)	External communication infrastructure
Hot metal typesetters	<i>US, UK and Germany</i> high investment in incremental improvement to mechanical machines	<i>US</i> informal know-how trading with Intertype
Analog phototypesetters	<i>US</i> in 1949 began high investment in optical engineering in 1953 complemented this with high investment in electrical engineering <i>Germany</i> investment in electrical and optical engineering for new development	<i>US</i> supplier relationships → informal consultation → outsourced computer subsystem for 'VIP' machine technology scanning consultant from Columbia for optical engineering <i>Germany</i> systematic study of strong local competitors (e.g. Berthold) technology scanning
Digital CRT phototypesetters	<i>US</i> exploratory investment in CRT hardware in late 1940s, but none thereafter investment in software development <i>UK (Linotype-Paul)</i> high investment in software and CRT hardware <i>Germany</i> high investment in software and CRT hardware	<i>US</i> technology scanning joint development with CBS Labs <i>UK (Linotype-Paul)</i> technology scanning strong ties to suppliers and users <i>Germany</i> technology scanning ties to strong local digital screening and printing sectors
Laser imagesetters	<i>US</i> high investment in software and laser hardware <i>UK</i> high investment in software and laser hardware <i>Germany</i> high investment in software and laser hardware	<i>US</i> technology scanning strong ties to suppliers <i>UK</i> technology scanning strong ties to suppliers <i>Germany</i> technology scanning ties to strong local digital screening and printing sectors

sections, Intertype and Monotype did not effectively leverage either of these factors.

Intertype

Like Mergenthaler, Intertype developed strong external integrative capability during the hot metal era. The firm made ongoing investments in incremental innovation, with new models matching almost every Mergenthaler innovation listed in Table 3. A strong informal communication network with Mergenthaler, given the identical architecture of the machines, resulted in an effective external communication infrastructure. Given their similarities, it is intriguing to try and understand why Intertype failed to make the transitions to subsequent generations of technology while Mergenthaler succeeded. In the following section, I contrast Intertype and Mergenthaler's evolution and argue that the failure to develop external integrative capability in subsequent generations and a lack of distributed R&D are at least partially responsible for Intertype's performance.

Intertype's initial foray into analog phototypesetting was driven by its hot metal developers, and the result, the Fotosetter, was an 'imitation hot metal' machine. Upon initial examination, it would appear that Intertype was on the right track in terms of integrating external technical knowledge. In designing the machine, they clearly lacked expertise in optical engineering, and therefore had Kodak assist in the development of the optical component of the machine. Unfortunately, they constrained Kodak's input to fit within the architecture of a hot metal machine—a mechanical architecture. Intertype was not developing any knowledge about electronics, a critical skill for the phototypesetter generation.

As the very first phototypesetter on the market, the Fotosetter had a monopoly and achieved reasonable level of sales with about 700 units shipped. The 'success' of the Fotosetter delayed the firm's investment in electronics. While Mergenthaler began investment in an electro-mechanical phototypesetter in 1950 after its decision not to pursue its 'imitation hot metal' machine, Intertype continued to make improvements to the Fotosetter. The Intertype 1956 Annual Report (p. 4) states, 'Your Corporation continues its research and development work in the field of photocomposition with special emphasis on enlarging the range of type and adding to the Fotosetter's utility.' Thus while the firm may have gained some expertise in optical engineering from its relationship with Kodak, it failed to develop electronics expertise.

In 1957 Intertype was brought abruptly into the electronic age when it was

acquired by Harris-Seybold. Harris, traditionally a printer manufacturer, had embarked upon an ambitious plan to transform itself into an electronics company (Rosenbloom, 1988). In the process, Harris had developed some technology that would be useful in phototypesetting: stroboscopic light selection of characters from a spinning disk.⁹ Recognizing the need for a font library in order to enter the industry, the firm acquired Intertype.

Intertype engineers worked with Harris' central R&D lab on the development of Intertype's first electro-mechanical phototypesetter, the Fototronic 480. While the engineers of both firms worked together, there is evidence that little technology was transferred. Since Harris had already done a great deal of the development work before the merger, Intertype had little to add. In addition, since Intertype's development group had little expertise in electrical engineering, they had difficulty internalizing what Harris did. Unfortunately, by the time the Fototronic 480 began shipping in 1964, Photon, a new entrant was already shipping a machine that was both faster and supported a larger number of fonts online. The Fotosetter 480 therefore did not do very well in the marketplace.

When Intertype subsequently decided to develop a low-cost phototypesetter, one that would not require the leading-edge electronics expertise of the central Harris lab, the firm contracted the development out. There was little confidence in the ability of the Intertype group to develop the machine on its own. Instead of having some internal employees interface with the external team, Intertype waited until the development was complete and then had its engineers examine the 'final product'. The Intertype engineers felt a strong need to redesign the product, and the machine's announcement was delayed by about a year. The original designers had no role in the redesign, and no technology was transferred from the outside team to the internal developers. The product, the Fototronic 600 was a dismal failure.

The lack of confidence in Intertype's development group and the subsequent disappointing relationship between Intertype and the external developers can be traced to a combination of factors. First, the lack of confidence in Intertype's internal development indicates that the firm did not successfully absorb technical knowledge from Harris' central lab. Since Intertype did not appear to invest a great deal in separate electrical expertise, the lack of transfer is not surprising—Intertype lacked absorptive capacity. Second, the relationship between Intertype and Harris' central R&D lab, while logical in that it leveraged Harris' expertise, also allowed the Intertype development group to become lazy in terms of establishing its own external

⁹ This technology was similar to that of Photon, the first new entrant, and a patent dispute between the two firms was settled out of court.

contacts. Since Intertype had in-house experts available at Harris, it failed to develop other relationships. So while individuals at Harris' central lab may have developed an external communication infrastructure, the engineers at Intertype did not. This may have further eroded confidence in the group.

With the CRT generation of technology, the lack of local expertise within the Intertype organization became apparent, and separate investments were made in establishing requisite skills there. The first development was still in collaboration with Harris' central lab, but Intertype also hired its own experts. With its broad portfolio of technology in multiple electronics businesses, Harris had better access to CRT technology and provided the initial external linkages. This time, however, more technology seems to have been transferred to Intertype, and subsequent machines were developed primarily by Intertype with minimal input from corporate. Unfortunately, although Intertype engineers began to assume greater responsibility for external communication, their lack of any prior infrastructure hindered these efforts. Thus despite internal investments in absorptive capacity the infrastructure necessary to transmit external information was slow to develop, and Intertype failed in the market. In addition to technical difficulties, the firm's position had already declined during the 1960s and 1970s when sales of analog phototypesetters were growing, and it may have had difficulty convincing buyers that it was competitive. By the early 1980s, when industry sales of CRT typesetters were increasing, Intertype's position had eroded to the point that Harris corporate eliminated investment in typesetter development and shifted strategic priorities to other electronics businesses. The last internally developed machine was announced in 1980, and Intertype stopped shipping typesetters in 1984.

Table 5 summarizes Intertype's development efforts. Despite strong performance in the hot metal generation, the firm failed to make internal investments in electronics, and therefore lacked the absorptive capacity necessary to effectively transfer technology either from external sources or from Harris corporate. When investments in new capability were finally made in the CRT generation, lack of a prior external communication infrastructure hindered the firm's ability to develop strong new relationships. In addition, since all development took place in the US, Intertype could not leverage multiple locations as Mergenthaler had.

Monotype

Early in the hot metal era it appeared Monotype might benefit from multiple development groups in a manner similar to Mergenthaler. Tolbert Lanston, a

TABLE 5. Intertype Product Development History

Generation	External integrative capability	
	Internal investments in knowledge (absorptive capacity)	External communication infrastructure
Hot metal typesetters	high investment in incremental improvement to mechanical machines	informal know-how trading with Mergenthaler
Analog phototypesetters	in 1937 began investment in optical engineering but never invested significantly in electrical engineering	optical system from Kodak Harris corporate R&D provided electronics expertise
Digital CRT phototypesetters	high investment in both software and CRT hardware	limited ties to electronics community
Laser imagesetters	no entry into this generation	no entry into this generation

US civil service clerk, invented the original Monotype machine, and the Lanston Monotype Corporation was founded in the US in 1890. British rights to the invention were sold in 1897 and the Lanston Monotype Corporation was founded in England. Early on, all development and manufacturing was done in the US, but after World War I, the UK organization expanded and took on both tasks. The Monotype machine had been much more successful in the UK, the rest of Europe, and in underdeveloped nations (the sales territory of the UK firm) than in North and South America (the territory of the US firm), and the UK organization felt the need for independence. In 1931, the UK firm changed its name to The Monotype Corporation Limited and formally separated from the US company. So while development was ongoing both in the US and the UK, there was little communication between the two groups. Over the next 20 years, the UK company continued to grow, and the US company, perhaps due to more intense competition from Mergenthaler and Intertype in their home country, faltered. In 1970, the assets of the US firm were sold to American Type Foundry and development of the Monotype hot metal machine in the US stopped, with any further advances coming from the British company. The US organization never engaged in development of any other technological generation.

Unlike Mergenthaler and Intertype, Monotype did not develop external integrative capability in the hot metal generation. While Monotype made ongoing investments in incremental innovation in both the US and UK, it never developed an external communication infrastructure. The Monotype

architecture was so different from the linecaster architecture that there was little utility in engaging in any know-how trading with either Mergenthaler or Intertype. This lack of an external communication infrastructure hurt the firm in future generations.

Monotype's first series of analog phototypesetters, the Monophoto Mark 2–Mark 5 were 'imitation hot metal' machines developed by the hot metal organization, and they used the Monotype hot metal architecture. They were mechanical machines with an optical subsystem. As a result, Monotype, like Intertype, developed a large stock of internal knowledge in optical engineering but none in electronics. In addition, since the Monophoto's internally focused hot metal group was doing the development, there was little interaction with external sources of knowledge and no development of a communication infrastructure.

In the mid-1960s, while the rest of the industry was developing electro-mechanical machines, Monotype was not even investing in electronics. The lack of absorptive capacity combined with no external communication infrastructure made the firm myopic in terms of recognizing the importance of new technology. One Monotype employee from 1963 to 1969 made an attempt to increase the firm's awareness of external technology and commented in a 1994 interview, 'I became a one-eyed man in a blind kingdom.' When Monotype did finally develop an electro-mechanical machine, the Monophoto 400 in 1969, it was not technically competitive with other machines on the market. The firm did not explicitly involve external sources and given the lack of external communication infrastructure, its ability to informally access external knowledge was limited. It is not surprising that the resulting machine performed poorly. After the Monophoto 600, the development group took a step backward and developed a machine that once more incorporated elements from the hot metal architecture. This machine, the Monophoto 400 was described as, 'an odd amalgam of mechanics, fluidics and electronics . . . with anachronistic technical concepts which ran counter to prevailing development trends' (Wallis, 1993, p. 4).

Monotype's lack of an external communication infrastructure also hurt it in terms of recognizing the significance of CRT technology. While the rest of the industry was beginning to invest in CRT technology, Monotype was continuing to work on the prior generation. Ronald McIntosh and Peter Purdy, inventors of the Linotron 505 at K. S. Paul (eventually acquired by Mergenthaler) originally approached Monotype with their technology. They had received a grant from the British government, and if they sold the technology to a foreign firm the grant would have to be repaid, so they were looking for a UK buyer. Mr McIntosh stated in a 1994 interview that he was

TABLE 6. Monotype Product Development History

Product	External integrative capability	
	Internal investments in knowledge (absorptive capacity)	External communication infrastructure
Hot metal typesetter	<i>Salfords, UK</i> high investment in incremental improvement to mechanical machines	<i>Salfords, UK</i> none
Analog phototypesetter	<i>Salfords, UK</i> high investment in optical engineering in 1946 but none in the crucial area of electrical engineering until 1967	<i>Salfords, UK</i> none
Laser imagesetter	<i>Salfords, UK</i> no investment <i>Cambridge, UK</i> high investment in software and laser hardware with new engineering group	<i>Salfords, UK</i> no investment <i>Cambridge, UK</i> integration into Cambridge University scientific community

so appalled by the reply of Mr J. Matson, president of Monotype, that he wrote it down on a sheet of paper which he had kept all these years. 'We see nothing that will equal the excellence of our [hot metal] product in the next 25 years', was what Mr Matson told the two inventors. Monotype was clearly not interested in what they had to offer. In the end Monotype failed to invest in the CRT generation.

By the mid-1970s Monotype was experiencing a financial crisis. Its market share of phototypesetters was extremely low—about 1%—and hot metal sales could no longer sustain the firm. Drastic measures were necessary, and so the firm finally looked outside for technology. Monotype was lucky to find David Hedgeland, an inventor who had been working on laser applications in the graphic arts. They hired him, and he built a development group comprised of other outsiders to work on a laser imagesetter. The group was based in Cambridge as opposed to Salfords, where the rest of the Monotype organization was housed. The resulting Lasercomp was a major technical accomplishment and the first laser imagesetter in the industry.

Like Mergenthaler, Monotype benefited at this point from having geographically distributed R&D locations. While Hedgeland and his group were developing the laser machine, the Salfords group was continuing to

make incremental improvements to the hot metal machine. In fact, as late as 1982 Monotype announced the ability to interface a video editing system with their hot metal caster. Clearly a new location was needed to overcome the organizational routines and procedures of the Salfords group, and Cambridge appears to have worked.

Hedgeland also changed the company's attitude towards external technology. His development group was much more integrated with the external technical community, including ties to the academic community in Cambridge. Monotype thus developed external integrative capability in the laser generation through both internal investments in R&D and ongoing communication linkages.

Despite its successful technical accomplishment, Monotype's commercial recovery was slow, and the British government's National Enterprise Board had to organize a rescue plan in 1978. While Monotype initially led the industry with the first laser imagesetter, its commercial reputation and the strength of its international sales and service network had declined to the point that it had difficulty selling the product. While the machine garnered a reasonable share of the market early on, once competition entered, Monotype's share declined precipitously. Although the firm has managed to survive,¹⁰ its cumulative share of the laser generation through 1990 was only about 5%, and its annual share in 1990 was closer to 3%.

Table 6 summarizes the product development activities of Monotype. The firm failed to develop external integrative capability in either the hot metal or analog phototypesetter generations, resulting in a series of disappointing phototypesetter products and the firm's gradual demise. In the laser generation the firm recovered somewhat with assistance from the British government. The combination of a separate development location and a new development group with strong external ties to the scientific community resulted in a leading-edge product. By that time, however, the firm's supporting sales and service infrastructure along with its reputation had weakened, and the commercial performance of the product was mediocre.

6. The Role of External Integrative Capability

External Integrative Capability Matters

The details of the case studies demonstrate the importance of both elements

¹⁰ Monotype had split into three separate firms as of 1990. One firm is carrying on with maintenance and supplies for remaining hot metal systems, one firm owns the font library and is licencing it, and the third firm develops and sells imagesetter systems.

of external integrative capability, internal investments in absorptive capacity, and an external communication infrastructure. Without internal investments in absorptive capacity, firms were not particularly successful at integrating external knowledge. For instance, not having invested much in CRT technology itself, Mergenthaler did not benefit from technology transfer in its collaboration with CBS. Similarly, Intertype did not benefit from its collaboration with Harris' central R&D lab in the analog phototypesetter generation.

Small internal investments, did appear, however, to help in the identification of relevant external technologies. Mergenthaler's early investments in CRT technology combined with the joint development with CBS Labs, while not enough to result in successful technology transfer, did help the firm to identify K. S. Paul and value its technology. In contrast, Intertype and Monotype passed by the opportunity and failed to develop viable products on their own.

While internal investments in absorptive capacity are important, the development of an external communication infrastructure to transmit knowledge is equally critical. The communication linkages by which external knowledge is transmitted cannot be assumed to exist, and in fact are a significant source of firm heterogeneity. The contrast between Monotype and Mergenthaler in the transition from hot metal to analog phototypesetting provides an example. Despite internal investments in R&D, first in optical engineering and later in electronics, Monotype was not successful in absorbing external knowledge. The engineers had not engaged in ongoing relationships with outside sources and technology scanning was minimal. Mergenthaler, in contrast, both invested in the new technology and established outside contacts and was much more successful.

External Integrative Capability is Cumulative

If external integrative capability is so important, why don't firms just develop it during periods of radical technological change when it becomes clear that the capability is needed? The case studies provide evidence that both elements of external integrative capability are complex and cumulate over time; rapid development is therefore not feasible. Firms must invest in this capability during periods of incremental technological change in order to take advantage of it when radical technological change requires the firm to access external technology.

Cohen and Levinthal's (1990) work emphasizes the dynamically self-reinforcing nature of investments in absorptive capacity. Although

Mergenthaler invested early in absorptive capacity in each generation, it did not immediately integrate external knowledge and perform well. The first development projects were generally mediocre despite the attempt to integrate external knowledge. The initial investment, however, had the spillover benefit discussed by Cohen and Levinthal in that the prior related knowledge accumulated during initial developments helped the firm to absorb external knowledge in subsequent projects. If one examines the series of projects in each generation for Mergenthaler, there is a clear upward trend in terms of the product's performance. Mergenthaler's initial foray into phototypesetting, the Linofilm, was not very successful relative to new entrants' products, but it helped to build absorptive capacity, and future products such as the VIP were more successful. A similar pattern emerges in the laser generation. While the Omnitech 2000, the first laser imagesetter, was not very successful, Mergenthaler learned about the technology through working with the laser scanner experts, and subsequent developments were more successful. This result is consistent with empirical work in optoelectronics (Miyazaki, 1994), which finds that building new technological competence is a cumulative path dependent process.

One concern that arises about investments in absorptive capacity is that firms will not recognize the importance of investing in absorptive capacity in an unrelated area given their lack of prior related knowledge in the area. As Cohen and Levinthal state: 'the firm needs to have some absorptive capacity already to value it' (1990, p. 138). In contrast, I find that the external communication infrastructure developed in one technological domain helps a firm to develop absorptive capacity in a new unrelated technology. Firms that had developed strong external linkages in a prior technology were able to recognize unrelated, competence-destroying technologies and make initial investments despite a lack of prior related knowledge. Ongoing technology scanning and other communication linkages provided incumbents with an awareness of the new technology. For instance, even in the late 1940s, when post-war demand had driven hot metal sales to their highest levels since the 1920s, Mergenthaler became aware of CRT technology and did some preliminary research. Similarly Mergenthaler's awareness of laser technology came from contacts that the British development group had during the CRT era. Intertype invested in CRT technology, although it was external linkages at the parent company, Harris, that most likely resulted in the recognition of the technology's importance. In contrast, Monotype never developed strong external communication infrastructure in analog phototypesetting. Therefore, when the transition to CRT technology began, the firm was unable to

recognize its significance and never even invested in the technology. By the time the firm recognized its folly, it had already missed the generation.

An external communication infrastructure in a prior technology also helps in the development of it in a new technology. The infrastructure that supports the integration of external knowledge must be built over time. Informal know-how trading networks, for instance, are based upon trust and work as tit-for-tat relationships (Schrader, 1990). If a firm's employees are not part of a network during an incremental era, it will be difficult to join in once radical change is taking place.

It is possible that the relevant know-how trading network for a new technology may be different from the old technology, in which case one could argue that the prior relationships have no value. Even in this case, however, individuals in the firm may be better at establishing new relationships than someone who had never participated in such a relationship. In addition, at an institutional level, the firm anticipates acquiring technology from outside and immediately begins to set up linkages in the new technical domain—scanning of patents and technical journals in the new area is quickly formalized.

The contrast between Mergenthaler, Intertype and Monotype in the transition from hot metal to analog phototypesetting provides an example. Given their history of informal know-how trading, both Mergenthaler and Intertype were accustomed to finding valuable external technical knowledge. In their first phototypesetter developments, both firms therefore found external sources for the optical subsystem and worked with those firms to develop expertise. Monotype, on the other hand, was both geographically and technologically isolated during the hot metal era and did not develop a culture used to looking for outside solutions. It therefore depended on its own internal engineers to develop the first phototypesetter, without any explicit external technology.

The importance of an external integrative capability is consistent with prior work (Henderson, 1994; Iansiti and Clark, 1994). These studies also suggest, however, that internal integrative capability in the form of cross-functional teams is important. Although the lack of detailed data about the structure and communication patterns of product development teams going back to the 1950s precludes a careful test of the role of cross-functional teams in the typesetter industry, interviews suggest that there were not widespread differences among the three firms examined. The initial shift to analog phototypesetters took place in the 1950s and 1960s before the use of cross-functional teams had been popularized. All three firms had formal organizations with traditional functional affiliations and weak as opposed to 'heavy-weight' (Clark and Fujimoto, 1991) project management. All three

firms also experimented with cross-functional teams in the 1970s and 1980s as the structure gained more popular appeal. It is possible that Mergenthaler was more effective at implementing cross-functional teams, but unfortunately a lack of data precludes this comparison.

7. *The Value of Geographically Distributed R&D*

There are clearly trade-offs involved in having multiple internationally distributed R&D locations. The possible duplication of effort and the increased cost of and need for communication argue against the configuration. On the other hand, traditional arguments in the multinational management literature for having multiple locations (Terpstra, 1977) include access to cheaper labor, access to better technical resources, and proximity to the market. This study provides an additional argument in favor of distributed R&D—it helps create dynamic capability.

Mergenthaler clearly benefited from having a global network for technology development. There were three primary benefits to having multiple locations. First, a sense of internal competition among the US, UK and German development groups spurred innovation. Despite the cooperation and shared learning that occurred among the three groups, interviews with developers from each country indicated that each group had a strong sense of pride and wanted to demonstrate its superiority. Mergenthaler particularly benefited from this dynamic in the CRT generation, where UK and German developers both shared technology and competed strongly, resulting in a series of leading products from both teams.

Intertype did not benefit from such a dynamic. While Intertype worked with Harris' central R&D lab, the two organizations were not in any way competing—Harris was a resource for Intertype and the organizations cooperated. Monotype may have benefited from a sense of competition when it established a separate development organization for the laser generation, although interviews did not indicate such a dynamic. Since the original organization was working on an entirely different technology, developers may have felt comparisons were not relevant.

The second benefit to multiple R&D locations arises when generations of technology overlap. In this case a firm can benefit by developing different generations in different locations. Mergenthaler was able to overcome some of the organizational inertia which hinders many transitions by using multiple locations. For instance, while the US development group focused on analog phototypesetter development, the UK and German groups focused on CRT development. Laser development then began in the US while analog

phototypesetter development was winding down, and the UK and German groups continued to work on CRT machines. Monotype was also able to benefit from this effect with its successful laser development. The firm's failure in the analog phototypesetter generation had clearly indicated an inability to overcome the inertia of the routines and procedures embedded in the Salfords hot metal organization, so the new development group was located in Cambridge.

The final benefit of multiple locations is the ability to leverage different institutional environments. Burgelman (1991, 1994) points out the importance of intra-organizational evolutionary processes to firm survival, and identifies the need for internal variation, followed by selection and retention. By operating in multiple environments, Mergenthaler had built-in variation. For instance, the strength of the printing press industry in Germany provided Mergenthaler with strong ties, and helped the firm to understand how technological changes in printing presses might affect typesetters. At the same time, the strong history of high-quality typography in the UK provided Mergenthaler with insight into typefaces, and the US organization could tap into the strength of the software sector. The reopening of a US office in the Silicon Valley after previously closing the US and UK development groups provides evidence of the importance of access to local expertise. Neither Intertype nor Monotype experienced this benefit.

8. *Discussion and Conclusions*

Recent management research has begun to explore dynamic capability, the ability of a firm to renew its capabilities (Teece *et al.*, 1992; Teece and Pisano, 1994). Empirical work examining dynamic capability, however, is still limited, in particular, work concerning the successful development of new technical capability in the face of radical technological change. Through a detailed comparative examination of the technological and competitive history of three firms in the global typesetter industry over a period of more than 100 years, this research contributes a clearer understanding of what comprises dynamic technical capability.

Since its inception in 1886, the typesetter industry has been shaken by three waves of discontinuous, competence-destroying technological change. Of the three leaders in the original generation of technology, Mergenthaler Linotype, Intertype and Monotype, Mergenthaler is the only firm successfully to traverse all three new generations of technology. A careful comparison of these three firms suggests two important factors that contributed to Mergenthaler's dynamic capability. First, the development of external

integrative capability during periods of incremental change helped with the absorption of external knowledge during periods of radical technological change. External integrative capability includes two elements: (i) internal investments in new technology in order to develop absorptive capacity, and (ii) an external communication infrastructure to facilitate the transfer of knowledge. That infrastructure can be informal as in the case of know-how trading, or quite formal as in the case of alliances or joint ventures.

Second, the utilization of multiple R&D locations facilitated transitions through three different effects. First, competition between multiple sites spurred innovation. Second, by utilizing different locations for different generations, the firm could overcome the organizational inertia which might be present in a given location. Finally, different locations provided an important source of internal variation and allowed the firm to take advantage of different local institutional environments.

While this work takes an important first step towards understanding differential incumbent performance in the face of radical technological change, it has limitations. All three incumbents in this industry benefited from the slow pace of technological substitution in that they could continue to earn profits on the old technology despite being behind in the new generation. Mergenthaler was therefore able to survive long enough to recover, despite its poor initial performance in the first shift to analog phototypesetters. If the pace of technological change had been more rapid, all three incumbents might have been eliminated. Similarly, all three incumbents were buffered from the effects of competition by complementary assets. Since the customer set, customer purchase criteria and distribution, for instance, remained relatively constant throughout most of this period, existing sales/service networks were useful across each generation of technology. When shifts require more fundamental changes in what customers value, then it is much more difficult for incumbents to adjust (Rosenbloom and Christensen, 1994). The possession of large proprietary font libraries also helped to buffer incumbents in the typesetter industry throughout this period. Since 1990, the industry has become much more competitive given the advent of Postscript, an open standard for fonts. Overall profitability in the industry, including that of Mergenthaler, has decreased substantially. Further work is needed to determine whether the mechanisms that helped Mergenthaler to survive, given the context of the technological shifts examined, still prove effective when slow substitution and complementary assets provide no buffer.

This research also raises a number of other issues that merit further exploration. Multiple research locations are costly and can sometimes lead to duplicative effort with little upside. It is crucial, therefore, to understand the

conditions under which the three benefits identified in this study outweigh the cost of multiple locations. While a competitive dynamic among research sites was helpful in this particular case, achieving the optimal balance of cooperation relative to competition can clearly be problematic. If distributed research sites experience too strong a sense of competition they may fail to cooperate when they should. Organizational mechanisms to achieve the optimal balance of cooperation and competition need to be explored. If the multiple research sites are developing the same technology, then the benefit of overcoming organizational inertia has limited applicability. This benefit may only be relevant during periods of relative technological turbulence when the firm can take advantage of locating different development efforts in different locations. During long periods of incremental technological change there is not a need to displace old organizational routines and procedures. Multiple research sites may also provide limited benefit if they are located in places with similar local environments—i.e. the benefit of local variation is only valuable if there is relevant variation to be had. Understanding what dimensions of variation are most important, however, is not a trivial task. While Porter (1990) identifies a number of factors that drive the competitiveness of an industry in a particular country, additional work is needed to understand the relative importance of these factors in terms of locating a research site in that country.

Finally, more work is needed to understand the trade-offs involved in the different levels of commitment used to access external knowledge. Mergenthaler benefited from a variety of mechanisms ranging from the minimal commitment of technology scanning to formal alliances with other firms to outright acquisition and integration of firms with relevant expertise. While technology scanning and alliances enable a firm to slowly develop new technical capability and integrate it with existing structures and capabilities, in some cases the need to move quickly may make acquisition of a firm that already possesses the capability more attractive. In Mergenthaler's case, after a failed attempt to develop CRT capability internally, acquisition and integration of K. S. Paul were crucial to the firm's successful transition. In other cases, the cost of acquisition may outweigh the benefit of immediate access to knowledge. Further work exploring these trade-offs is welcome.

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