What can we learn from the history of technology?

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Abstract

This article focuses on exploring what technology scholars and students of management of technology stand to benefit most by foraging through the history of technology. In order to show how historical sensitivity could sharpen scholarship, three strategies for complicating the simple are drawn from the historian's toolkit. Implications for research in technology and innovation management are discussed. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

The Management of Technology (MOT) is a field on the make. Over the last decade, interest in MOT has burgeoned. In the mid-1980s, the National Science Foundation, the National Academy of Science, and the National Institute of Standards and Technology, partially at the urging of Congress, began to advocate for and allocate money to MOT research. During the 1980s and 1990s new journals, such as Technology Management, Technology Studies, The Journal of Engineering and Technology Management and New Technology, Work and Employment, were founded to stimulate and disseminate the wellspring of research on technological change and the management of technology. Technology and Innovation Management became a recognized division of the Academy of Management in 1987. Finally, courses and books on innovation and innovation...
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management multiplied, became best sellers, and continue to be published at a rapid
rate.

As students of technology and innovation, we are fortunate to have a place at the
forefront of trends that are making history and that are also of considerable interest to
those who formulate corporate and national policy. The position guarantees us consid­
erable resources, a powerful audience, and perhaps most importantly an opportunity to
make a difference. People genuinely and desperately want to know how to make
innovations and technological change happen more efficiently and effectively with
greater predictability. Furthermore, at the core of MOT lie crucial but less frequently
discussed social and philosophical issues; for example, the implications of changing the
technical and economic infrastructure for existing institutions and the quality of every­
day life or the relationship between material and social causality.

When I experienced interest, was confusion. I found reading histories of technology
a social science.

I confess. What I was confusing was the idea of technology an especially rich vein in
which are embedded humanistic and humorous aspects, which some (including myself)
may not have appreciated sufficiently. In later years, I began to see the power of history
and to see more of the subtleties of the particular. As I read, I found that sometimes less
well-grounded than in history, I hoped to learn more from the history of technology
that I might find in the history of science. The problem with the history of technology
is that it is not the same as the history of science. Rather than the focus on trends in
technology, the history of technology focuses on the context of technological change.

As a confounding matter, I have found the history of technology an especially rich vein in
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undergraduates to Weiner as the ‘father of cybernetics’, pointing to *Cybernetics, or Control and Communication in the Animal and the Machine* (Wiener, 1948) as the desideratum of feedback. My certainty crumbled after I stumbled across the biography of Elmer Sperry (1860–1930) by Hughes (1971). Between 1909 and 1918, Elmer Sperry’s work on gyrostabilizers and gyrocompasses generated a stream of new control systems for ships, airplanes and naval artillery; all of which made use of the principle of feedback. Sperry even co-authored a number of mathematical papers on the cybernetics of gyrostabilization. In 1918, almost 40 years before Werner Von Braun terrorized London with his V2 rockets and was then rewarded for his effort with a prominent position in what was to become NASA, Sperry demonstrated the first pilotless flying bomb, which he called the aerial torpedo. The aerial torpedo was made possible by a complex electro-mechanical guidance and control system of Sperry’s design. In short, over the course of several days reading, the cybernetic revolution, which provides the backdrop for so much of my own thinking on technology and work, aged for me by nearly a half-century.

History can also confuse because historians are more likely than social scientists to adopt an ideographic or path-dependent view of events and social developments. Within complex, lengthy chains of details, root causes become ephemeral and starting points, hard to identify. To narrate situated stories of humans and machines, historians weave individual volition, material forces, institutional pressures and cultural beliefs into explanatory fabrics with no sharp edges and sometimes few clear-cut patterns. The result leaves the reader more accustomed to the tightly constructed, ‘just-so’ stories of the behavioral sciences with a richer, but less certain, sense of how social life works.

Finally, history is confusing because historians are more willing than most social and behavioral scientists to admit that their business consists of crafting interpretations. Historians expect, even encourage, multiple readings of what the rest of us consider the same events. Nor is history’s commitment to reinterpretation entirely ontological, although some historians do subscribe to radical relativism. What is interesting about history is that even the field’s realists traffic in reinterpretations by reconfiguring patterns of known details or by uncovering overlooked evidence that supports a new reading of the past. For example, most of Thomas Edison’s biographers portray him as a tinkering genius with little knowledge of science. The reexamination by Hughes (1976) of Edison’s writings indicates, however, that he was quite familiar with scientific theories of his day, at least those that were relevant to his work.

In sum, history appeals because it complicates the simple and, by doing so, leads one to question the taken for granted. I believe that it is by learning how to make the simple more complicated that students of the management of technology stand to benefit most by foraging through the history of technology. Complicating the simple is valuable because it spurs questioning and questioning reduces the chance of asserting too boldly what we think we know. As a consequence, we are likely to formulate better theories and fall victim to fewer blindspots, though perhaps at the cost of less confidence. To see how historical sensitivity could sharpen scholarship, consider the utility of three strategies for complicating the simple drawn from the historian’s toolkit. For lack of established terms, I will call these strategies: typifying the atypical, connecting the discontinuous, and transcending contraries.
3. Three strategies from the historian’s toolkit

3.1. Typifying the atypical

Regardless of the time in which they live, people seem to believe that their own era is somehow unique. In the popular media of most periods, one finds writers proclaiming just how distinctive contemporary achievements and experience appear to be when compared to what has gone before. Although some writers laud and others disparage their present, few dispute its atypicality. Yet, no form of simplification is more vulnerable to the historian’s craft than unqualified claims of uniqueness. As a scholarly strategy, typifying the atypical strengthens circumspection by highlighting unanticipated similarities rather than differences, a quality often lacking in managerial discourse on technological change, especially when the discourse borders on futurism and the technology under discussion holds forth the promise of a new market. To see how students of contemporary technology might benefit by learning to typify the atypical, consider the widespread claim that technological change is faster today than ever before.

3.1.1. The pace of change

The odds are that within the first 20 pages of any recent book on technical and economic change, especially one that has made its way to the corner bookstore, will be a statement, if not an entire chapter, on how fast things are changing. Like the authors of these books, most of us believe that our world is being turned upside down more quickly than any world that came before. Despite its popularity, however, the reality of an unprecedented rate of change is debatable and depends upon the evidence one uses. Many of the technologies that undergird our way of life, including electric power, the electric motor, the telephone and the internal combustion engine were invented between 1875 and 1925. As a reminder of just how fertile a period of innovation the late 19th and early 20th centuries were, Fig. I provides but a partial list of the technologies that led commentators of the day to proclaim that theirs was also an era of unprecedented change. For example, the President’s Research Committee on Social Trends (1933) wrote of the automobile, “It is probable that no invention of such far reaching importance was ever diffused with such rapidity or so quickly exerted influences that ramified through the national culture transforming even habits of thought and language (p. 172).” Given that identical statements are now made daily about computers or, more broadly, about digital technology, it is worth pondering whether today’s technologies are indeed changing society more quickly or thoroughly than did the technologies of the

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Unles, of course, it is the claim of typicality itself. Some historians argue that all events are unique. In fact, one of the central tensions in history consists of the struggle between uniqueness and representativeness. Rather than choosing between nominalism or its reverse, I believe that it is more practical to see each epistemological stance as an analytic tool that can be put to good use. Here I am interested in countering excessive and often unrecognized nominalism in the rhetoric, as opposed to the empiricism, of MOT.
1876 Telephone demonstrated
1877 Phonograph (hand cranked)
1879 First incandescent light bulb.
1881 Refrigerated Railroad car first used
1882 First use of continuous processing technology (oatmeal)
1883 Machine gun
1884 First long distance phone service
1885 Internal combustion engine (Benz and Daimler)
1886 First desk telephone
1887 First modern calculating machine
1888 Telsa demonstrates the AC electric motor
1889 Punch card tabulators (Hollerith machines)
1890 Mimeograph machine
1895 Marconi demonstrates radio
1896 First telephone
1897 First vending machines
1898 First zeppelin
1899 First electric sewing machine
1900 First vacuum cleaner
1901 First radio broadcast
1902 Sperry's gyrocompass
1903 Non-experimental transatlantic radio conversation
1906 Vacuum tube (De Forest)
1907 First radio station
1909 Bakelite
1910 Synthetic rubber
1911 Sperry events analogue computer for navigational uses.
1913 Ford's Highland Park assembly line.
1914 Teletype
1915 Transcontinental telephone service. (U.S. San Francisco)
1920 First radio broadcasting station
1924 First diesel locomotive

Fig. 1. Chronology of key technological developments: 1876–1924.

Second Industrial Revolution. On this issue, historical data and historians counsel caution.

For example, Fig. 2 plots a measure of the diffusion of five technologies that most commentators agree have transformed society: two from the turn of the century (the automobile and telephone), two from mid-century (radio and television) and the icon of contemporary technological change, the personal computer. The figure displays diffusion as the percentage of American households that owned each technology as a
Fig. 2. Percentage of US households with specific technologies by year after invention.

function of the number of years since the technology's invention. The data came from a variety of sources. Information on telephones, radios and TVs up to 1970 came from Historical Statistics of the United States: Colonial Times to 1970 (United States Department of Commerce, 1989, p. 783, 796). For later years, I drew data on phones and TVs from The Statistical Abstract of the United States, 1994 (United States Department of Commerce, 1995) and TV Dimensions '97 (Media 1997). The percentage of households owning automobiles as well as the percentage owning telephones before 1922 were estimated from Fischer's graph (1992) (p. 22) depicting the diffusion of turn-of-the-century technologies. Fig. 2 offers two estimates of the percentage of households owning personal computers. The less conservative estimate was constructed from data compiled by Marvin Sirbu at Carnegie Mellon University (http://www.cs.cmu.edu/afs/cs.cmu.edu/user/bam/www/numbers.html#ComputerInHomeWork) and from a recent poll conducted by Dataquest (http://gartner12.gartnerweb.com/dq/static/about/press/pr-b9765.html). The more conservative estimate was based on data collected by the U.S. Bureau of the Census during its 1984, 1989 and 1993 Current Population Surveys (CPS) and published in the report, 'Computer Use in the United States: 1993' (http://www.census.gov/population/socdemo/computer/comp1.txt).

From one perspective, Fig. 2 seems to vindicate popular perceptions of an increasing pace of technological change: the curves indicate that the lag between invention and significant diffusion was shorter for the personal computer than for prior technologies. 2

2 The plots are based on the following dates of invention: (1) 1876, the year Alexander Graham Bell demonstrated the telephone, (2) 1887, when Karl Benz exhibited his third prototype automobile at the Paris Exposition, (3) 1906, the year of the first radio broadcast (4) 1925, the first demonstration of a TV broadcast, (5) 1975, the year MITS introduced the Altair personal computer and Microsoft was founded.

3 Historical Statistics lists the percentage of households with telephones and the number of household with radios and television. I used census data on the annual number of households in the US to calculate percentages for the latter two technologies. Data on the number of households came from the United States Department of Commerce (1989), pp. 42–43, and from the U.S. Bureau of the Census (1997), www.census.gov/population/socdemo/hh-fam/rep96/96hh1.txt.
Twenty percent of US households owned a personal computer roughly 13 years after its invention. It took 21 to 25 years for the same percentage of households to own radios and televisions and 30 years for automobiles and telephones. Thus, the lag for radio and television was also shorter than the lag for the telephone and automobile. The fact that ever more recent technologies evince successively shorter lags can be interpreted as evidence of an escalating pace of change.

Focusing on lags to diffusion, however, does not tell the figure's entire story. Note that once the diffusion curves for televisions and radios turn upwards, their slopes appear similar to, if not steeper than, the slope of both curves for personal computers. Although the data stream for personal computers is not as lengthy as that for radios and televisions, as of 1997 there was no reason to believe that personal computers had found their way into American homes more quickly than did either radios or televisions, once the latter began to diffuse. In fact, if one adopts the more conservative, CPS estimates of the personal computer's diffusion into households, there is no doubt that the purchase of TVs and radios escalated more rapidly! Thus, the data in Fig. 2 provide, at best, ambiguous support for the widespread claim that the pace of technological change is quicker today than ever before.

One can argue that the diffusion of personal computers does not adequately capture the pace of digitization. If other measures were used (perhaps the number of microchips sold), the evidence might be less ambiguous. This could be true. Others might argue that the computer revolution has really occurred in the workplace and that, therefore, household data do not adequately capture the change. There is merit in this argument as well. My objective in presenting the data in Fig. 2 is not to 'prove' that claims about the pace of change are 'wrong', but merely to suggest that the warrant for such claims should be treated with considerably more skepticism than is often the case. The pace of modern change may be less atypical than we think.

More importantly, statements about the pace of change in today's world are often not simply meant to denote an escalating rate of diffusion. Most authors also mean to suggest that the subjective experience of having one's world turned upside down has intensified as well. On this score, I believe history counsels even more caution than it does about rates of diffusion. People who were 50 years old in 1930 were born into a world of horses and wagons where people could only talk face-to-face, where flying was reserved for birds, where fire remained the only means of chasing off the night, where firms were small, and where management was an unknown occupation. At 50, the same people probably drove automobiles, worked for a large corporation, had electricity in their homes, routinely talked to friends and neighbors from remote locations via telephone and if they had sufficient income, could even fly from one place to another. From our position in time it is easy to underestimate the way in which electricity and

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It is important to keep in mind that lags to diffusion depend not only on delayed consumer purchasing but delays in availability. Although 'invented' in 1925, televisions were not mass produced until 1950. Hence, most of the lag in TV's diffusion curve indicates a lack of availability. The personal computer, was brought to market much more quickly. If one were to correct for 'availability', the lag for television and radio would be less than or equal to the lag for personal computers.
automobiles, in particular, changed social structures, family structures, temporal structures, patterns of mobility and ultimately the tenor of everyday life and people's images of themselves (see, Fink, 1976; Nye, 1990).

Our temporal position also makes it easy to overestimate the effects of the computer on our daily lives. Not all technologies that alter the social system significantly change the quality of our subjective experience or our sense of self. In retrospect, it seems clear that the telephone altered how people did business and our culture's perceptions of time and space. Commentators at the turn of the century also thought that the telephone would change people's moral and social lives. Fischer (1992) (p. 1) notes, for example, that in the 1920s common questions were 'Does the telephone make men more active or more lazy?' and 'Does the telephone break up home life and the old practice of visiting friends?' Yet, as Fischer painstakingly shows, texts that chronicle everyday life of the period as well as interviews with people who experienced the spread of the telephone indicate that most people adopted the phone with little fanfare and with little evidence that it changed their perceptions of themselves or their lifestyle. The automobile, by contrast, was far more revolutionary. At present, we have very little data on what computers and other digital technologies are doing to our lives or our sense of self. It may be that the computer will be as revolutionary or even more revolutionary than the automobile, but it may also be that the computer will turn out to be no more subjectively transforming than the telephone.

3.1.2. International competition

Another theme routinely sounded in the MOT literature and open to the typifying influence of history is that of unprecedented international competition. Markets, we are told, have suddenly become international. In the 'global village' that we now believe we inhabit, MOT is especially important because technology and innovation are widely held to be the key to successful competition and, hence, economic survival. Thus, consultants and commentators routinely counsel managers to look not only to themselves but to other countries, especially Japan, for new technologies and for guidance on how to innovate more routinely.

There is no doubt that the economic order is changing and that the change involves the breakdown of national boundaries and markets, but the notion that globalization is a recent development and is, thus, atypical is shortsighted. As Beniger (1986) illustrates in great detail, economic activity has been becoming increasingly global since at least the 1700s. Moreover, globalization appears to have evolved in spurts linked to developments in technologies of control and communication. From this vantage point, today's flurry of international trade and competition seems to be merely the most recent escalation. Another quantum leap in globalization occurred shortly after World War I. Then, too, businessmen and politicians looked abroad for technologies and ideas about how to enhance their productivity and competitiveness in an increasingly international economy. The primary difference was that in the 1920s, all eyes turned to the US instead of Japan. The gurus of economic salvation, the Taguchi's and Demming's of the time, were Frederick Taylor, Henry Ford and Samuel Insull. The technological analogues of total quality management, just-in-time inventories and computer integrated manufacturing were the stop watch, the assembly line and the electrical grid.
Russia and Germany, in particular, turned to the US for models for improving productivity (Hughes, 1989; Guillen, 1997). The German economy had been destroyed in World War I and Lenin and Stalin hoped to raise from the ashes of the Russian revolution, a powerful industrial economy. Both countries imported large numbers of consultants from the US (as did other European nations), spent large sums of money on American technology and elevated Taylor and Ford to positions of cultural prominence (Sutton, 1968; Traub, 1978). As a result, European social scientists still refer to regimes of mass manufacturing as ‘Fordism’, a term rarely used in the United States. In 1924, Stalin wrote:

American efficiency is that indomitable force which neither knows nor recognizes obstacles; which continues on a task once started until it is finished, even if it is a minor task; and without which serious constructive work is inconceivable... The combination of the Russian revolutionary sweep with American efficiency is the essence of Leninism (cited in Dorn, 1979, p. 336).

To sense the similarity between recent American interest in Japanese manufacturing processes and German and Soviet interest in American systems in the 1920s, consider the following passage from Thomas P. Hughes’ American Genesis. Hughes recounts what Moog (1927) told the German public in his 1927 best selling book, *Over there Stands America* (*Drüben steht Amerika*), written after Moog made a pilgrimage to Ford:

Of the Highland Park plant (Moog) wrote, ‘‘No symphony, no Eroica, compares in depth, content and power to the music that threatened and hammered away at us as we wandered through Ford’s workplaces, wanderers overwhelmed by a daring expression of human spirit’’. Whirring and flashing machine tools, great presses sounding like artillery...and the turning, climbing and descending conveyors left indelible impressions. Afterward he saw the foundry and blast furnaces at River Rouge, the ‘‘colossal’’ spaces filled with immense numbers of workers so concentrated on their tasks that one could not exchange a word with another...Not impressed with the Spartan working conditions Ford provided, Moog took the high wages—and the worker-owned automobiles—to be a compensation. He met a Ford worker who earned 85¢ an hour and who in eleven years had saved $25,000, in part through speculation, ‘‘which almost all Americans do especially in a booming...[city] like Detroit.’ Recently that worker had traded his Ford for an elegant $1,100 Nash that now stood before the $2,800 house he had built. Moog found the self-sufficient Detroit workers full of spirit, unlike the sullen German workers with their downcast eyes. Organized plant tours and selected interviews probably persuaded him that Ford workers were satisfied by improvement in income and fulfilled by the realization that they were part, albeit small, of a historical transformation in the process of production. (Hughes, 1989, p. 291)

As Hughes intimates, from an American point of view, Moog’s perspective was skewed. Auto workers were indeed attracted to Ford’s five-dollar day, but few think of them as being particularly fulfilled. For example, annual turnover at the Highland Park plant at the time of Moog’s visit was over 300% (Hughes, 1989, p. 219)! The important lesson for students of MOT is not that Moog was a fool or even that he was fooled by
his tour guides, although they undoubtedly structured what he saw and perceived very carefully. Instead, the writings of Moog and others like him show us that international competition and its underlying asymmetries are neither as new nor as atypical as we sometimes think. They also encourage us to question whether the pronouncements of modern industrial pilgrims are any less tilted. From our perspective 70 years later, it is reasonably clear that we learn more about Moog and the Germany of his time by reading his book than we learn about Ford and Ford’s employees. It is worth contemplating whether the next generation’s historians may say much the same of contemporary American images of Japanese production systems.

The point is not that concerns about globalization and international competition are unfounded but only that these developments are not quite as unique as we sometimes perceive. Because history urges us to examine the possibility that modern economic challenges have elements in common with earlier historical periods, it helps us focus more clearly on what it is about modern economic conditions that are, in fact, different. These differences are likely to be in the details and not the general tenor of the times. Details are also integral for connecting the discontinuous, the second strategy for complicating the simple that historians sometimes employ.

3.2. Connecting the discontinuous

‘Discontinuities’ hold a prominent place in theory and research on the management of technology. In recent years, numerous scholars and researchers have warranted their work with the claim that industrial nations are again embroiled in a technological revolution, this time rooted in the spread of digital technology and the rise of an information (or service) economy (Negroponte, 1995; Barley, 1996a,b; Castells, 1996). Notions of discontinuity have also infused industry-level studies of technological strategy under the rubric of punctuated equilibria (Tushman and Anderson, 1986, Henderson and Clark, 1990), radical and incremental innovation (Nadler et al., 1995; lansiti, 1997) and the evocative image of Schumpeter (1934, 1942) of ‘waves of creative destruction’. Although I am not ready to discard the idea of revolutionary technology, reading the history of technology has made me less certain of what constitutes a technological revolution; for where some historians perceive revolution, others see evolution. Two books have been particularly influential in challenging my thinking about technological discontinuities, James Beniger’s The Control Revolution and George Basalla’s The Evolution of Technology. The first qualifies the notion that we are living through a period that deserves to be called the Information Revolution, the latter questions the idea that streams of technological development exhibit punctuated equilibria.

3.2.1. Information revolution?

Beniger’s central thesis is that the move to a digital infrastructure is but the continuation of a quest for adequate control systems that began in the mid-1700s. Beniger argues that steam and, later, electric power created crises of control. During their respective eras, steam engines, electricity and the internal combustion engine dramatically increased the speed of production and distribution. Existing social institu-
tions and ways of doing business proved inadequate for coordination. Communication channels, in particular, were too slow and the information they carried was too poor to provide the feedback necessary for controlling rapid production. The problem first came to light in the railroad industry. Trains traveled more quickly than administrators could send or receive messages and, thereby, pinpoint a train’s whereabouts. Especially prior to the telegraph, the results of increased speed and scanty information were unpredictable schedules as well as spectacular and all too frequent train wrecks.

Beginning with the spread of the telegraph and the rationalization of railroad administration in the 1850s (Chandler, 1977), American industrialists and inventors began to build systems to regain control over accelerating production and distribution systems. The components of the new systems were organizational as well as technological and, according to Beniger, included the construction of bureaucracies, the rise of scientific management, the advent of mass advertising, the development of real-time communication technologies including the telephone and radio, and an explosion of invention in the area of servo-mechanical controls and governors. In short, Beniger argues that organizational and technological history since 1880 traces a spiral of actions and reactions to escalating and evolving challenges to systems of control initially begun by the Nineteenth Century’s technologies of power. Digital technology represents only the latest installment of the trend.

There are numerous reasons to question Beniger’s interpretation. Among these are whether Beniger makes too little of qualitative differences in successive technological regimes, whether his view of history is more deterministic than events warrant, and whether actors understood their activities in the way Beniger portrays them. Even if the causes of information crises evince similarities, arguments about discontinuities often rest on distinctions between social responses and not causes per se. Nevertheless, after reading Beniger, specifying the nature and extent of major technological discontinuities becomes more difficult because Beniger shows that it is at least possible to blur, under a common theme, the boundaries of periods that most of us have been taught to perceive as distinct. Beniger’s work, therefore, leaves the claim that our era is somehow uniquely marked by an information crisis and an information revolution twisting a bit more precariously in the wind of time than it was before.

3.2.2. Evolution of artifacts

Whereas Beniger is a historian of systems, Basalla (1988) is a historian of artifacts whose research identifies the predecessors on which a number of presumably revolutionary technologies were modeled. Basalla connects the discontinuous more concretely than Beniger and at a much lower level of analysis. Basalla’s central point is that no technologies arise de novo. All are recombinations of previously existing, albeit sometimes obscure, artifacts or natural objects.

Basalla makes his point by revealing the hidden genealogies of devices that are typically portrayed as radical inventions developed out of nowhere by geniuses blessed with uncommon insight. For example, from Basalla we learn that Eli Whitney’s cotton gin was, in fact, a modification of a gin called a charka, that had been used in India for centuries to clean long staple cotton. Not only was the charka known to Italian artisans of the 12th Century, but Diderot (1751–1775) had included it in his Encyclopédie. Most
importantly, the charka was used during the 1790s by cotton growers in Louisiana and other parts of the South where Whitney first encountered it (Basalla, 1988, p. 33).

Basalla draws on previous work by Needham (1970) to dismantle the myth that James Watt invented the steam engine:

Popular accounts tell us that young James Watt was inspired to invent the steam engine as he watched steam rising from the spout of a tea kettle. The fanciful legend is undermined by the fact that working Newcomen steam engines existed in England at the very moment Watt was contemplating vapors... To complicate the matter further, Watt's version of the steam engine grew out of his dissatisfaction with a small scale model of a Newcomen engine he was asked to repair... In exchanging Newcomen for Watt as the inventor of the steam engine, the issue of continuity has not been resolved; the temporal focus of the investigation has merely been changed... Did the Newcomen engine appear on the scene without any antecedents? Again, the answer is no. Some of the mechanical elements that made up the Newcomen engine can be traced back to early seventeenth-century Europe, others had their origin in thirteenth-century China, and still others first appeared a century or two before the birth of Christ. (Basalla, 1988, pp. 35–37)

Perhaps, Basalla's most interesting case of connecting the discontinuous concerns the invention of barbed wire. American history tells us that barbed wire tamed the open range and, hence, the West by providing farmers with a way of thwarting ranchers' roving herds of cattle. Historians also tells us that barbed wire was invented more or less simultaneously in 1873 by three citizens of DeKalb County, Illinois: Jacob Haish, Issac Ellwood, and Joseph Glidden. Although barb-wire apparently had no artificial precursor, Basalla shows that even barbed wire did not spring full-blown from the mind of its inventors. Barbed wire was modeled on a natural object: a thorny shrub native to Texas, Arkansas and Oklahoma known as Osage orange. Prior to the invention of barbed wire, farmers in the West frequently used Osage orange to form hedge rows. Documents written by Haish explicitly acknowledge that he modeled his wire on the twigs of the Osage orange as did Michael Kelly who patented a 'thorny wire' 5 years earlier but who failed to commercialize his invention.

By showing that key inventions widely accepted as revolutionary were modeled on existing objects of which their inventors had first hand knowledge, Basalla reframes the problem that others have attempted to resolve by resorting to the idea of a technological discontinuity. Basalla's point is that because inventions always have identifiable precursors, even 'radical' inventions are not properly understood as discontinuities in a stream of artifacts. Technological change in and of itself is, therefore, more usefully understood as evolutionary rather than revolutionary. Nevertheless, what happens after a new technology appears is altogether another matter. Social and economic disjunctures may indeed occur.

Thus, Basalla does not deny that Whitney's gin, Watt's steam engine, or barbed wire had incredible and even revolutionary socio-economic effects. He simply suggests that scholars cannot adequately account for these effects by taking refuge in the idea of a technological discontinuity. Once one accepts the proposition that even 'radical' inventions are not technologically discontinuous, such questions as why some new technolo-
gies are adopted when others are not, why some of the latter have more ‘impact’ and why some of those with greater impact are perceived as revolutionary become more challenging as well as more interesting.

Basalla helps us understand that the phenomena that we hope to explain with the notion of technological discontinuity are more complicated and more socially, culturally and economically situated than theories of technological discontinuity imply. By resorting to a language of technological discontinuity, researchers risk oversimplifying social processes and, at worse, creating the illusion of an explanation. Fleming (1997) has recently argued that if one examines how theorists of technological change actually identify technological discontinuities (rather than how they formally define the term), one finds that they usually warrant the term by pointing to evidence of disjunctures in economic performance that follow the emergence of a technology rather than evidence of disjunctures in technological knowledge itself. If Fleming is right, then the concept of a technological discontinuity may sometimes entail tautological reasoning. Fortunately, the critical issues for students of MOT is not whether technologies are continuous or discontinuous but how new technologies arise and whether any particular technology allows us to do things we could not do before, why it does so, and with what ramifications. By attempting to connect the discontinuous, Basalla helps us focus more clearly on the practical as well as the theoretical task at hand.

3.3. Transcending contraries

Questioning the utility and accuracy of notions of technological discontinuities leads to deeper problems confronting students of technology as well as to the third strategy for complicating the simple that I wish to discuss. Because those of us who study technology labor at the boundary between physical and social phenomena, sooner or later we must take a stand, if only implicitly, on two dilemmas that have plagued Western philosophy since the Ancient Greeks. The first is the problem of determinism vs. voluntarism, popularly known as the problem of ‘free will’. Determinists hold that human behavior is caused by forces and conditions that exist independently of and typically prior to the behavior of interest. More often than not, these forces are external to the actors themselves. From the determinist’s perspective, humans are pawns of a system, be it technological or cultural. Voluntarists, by contrast, hold that human behavior is predicated on the choices that actors make. Under the doctrine of voluntarism, we are authors of our existence. The second dilemma, materialism vs. idealism, concerns types of causes rather than the nature of causality itself. Materialists hold that human action stems from physical contexts and causes such as geography, biology, climate, and technology. Conversely, idealists argue that ideas, norms, values, ideologies and beliefs are what drive human action.

The two dichotomies are often conflated in that writers fail to distinguish between determinism and materialism, on one hand, and voluntarism and idealism, on the other. Discussions of determinism, therefore, frequently assume that determinists also advocate materialism and that voluntarists advocate idealism. However, the antinomies of determinism vs. voluntarism and materialism vs. idealism are orthogonal and can be used to cross-classify stances toward technology in a way that reveals overlooked differences
among scholars and schools of thought. Fig. 3 illustrates such a cross-classification. Materialistic determinists speak as if technologies and other physical artifacts directly cause social phenomena. The work of Beniger (1986) has this flavor as do those passages in Karl Marx’s writings associated with the doctrine of ‘historical materialism’, the claim that relations of production rest on forces of production. Marx’s most famous statement of historical materialism comes from *The Poverty of Philosophy*: ‘The hand mill’, wrote Marx, “‘gives you society with the feudal lord, the steam-mill, society with the industrial capitalist’” (Marx, 1963). In the management of technology, theories of technological discontinuity and many studies of the ‘impact’ of computers on work are both materialistic and deterministic (e.g., Haug, 1977; Daft and Lengel, 1986).

Idealistic determinists, on the other hand, argue that socio-technical trajectories are driven by cultural ideologies. The break of Braverman (1973) with classical Marxism rested precisely on his claim that the history of Twentieth Century capitalism was driven not by forces of production but by a managerial ideology of control whose central premise has been the separation of execution from cognition. According to Braverman, technologies have played a role in the historical degradation of work because that they have often been designed with this objective in mind and, hence, are manifestations of ideology. The argument of Ellul (1964) that Western science and technology are driven by an infatuation with rationality and efficiency, which Ellul called ‘la technique’, is another example of idealistic determinism. Although materialistic and idealistic determinists usually offer different explanations for the same phenomena, both tend to weave webs of causality from which it is nearly impossible for humans to escape.

Like materialistic determinists, materialistic voluntarists believe that technologies more or less directly shape human behavior, but they also argue that because technologies are designed and because designs can be altered, humans can affect the social impact of a technology by redesigning it or refusing to adopt it. Materialistic voluntarism motivates the field of ergonomics (see Chapanis, 1976), the literature on human computer interaction, and the emerging field of computer supported cooperative work. In all three, the objective is to learn why some designs affect users positively and why others affect users negatively in order to eliminate the latter and promote the former. Political theories of information systems also evince an aura of materialistic volun-

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Fig. 3. Epistemological orientation of writers and schools of thought on technological change.
tarism: groups choose technologies in order to exert influence over other groups (Markus, 1983, 1984; Kling and Iacono, 1988).

Finally, idealistic voluntarism is the stance commonly associated with the social construction of technology (Bijker and Pinch, 1987; Barley, 1986), even though some social constructionists actually advocate variants of materialistic voluntarism, for example, the concept of Barley (1988) of ‘interpretive materialism.’ Idealistic voluntarists hold that a technology’s effects are rooted in the beliefs and values of designers and contend that one can change the effects of the technology by changing designers’ images of users. The notion that users shape a technology’s meaning and, hence, its constraints and affordances in the process of using the technology is also consistent with idealistic voluntarism (Orlikowski, 1992).

Despite the fact that most philosophical debates among students of technology have occurred between materialistic determinists and idealistic voluntarists along the main axis of Fig. 3, empirical evidence undermines any warrant for taking a strong stance on either dimension. Strong determinists have difficulty explaining how the same technology can trigger different social dynamics in similar contexts. By contrast, voluntarists are challenged by technologies whose effects prove impervious to the intentions of their designers, implementers and users. Advocates of materialism trip over data that show that differences in organizational culture can shape the impact of identical machines. Finally, staunch idealists have difficulty explaining why the assembly line had similar effects on relations of production in US and Soviet factories even though the ideologies of the two economic systems clearly differed.

Unlike the management of technology where such meta-theoretical issues rarely surface, historians of technology have repeatedly grappled with issues of determinism, voluntarism, materialism and idealism. Although many have also lined up in positions along the main diagonal in Fig. 3, a number of historians have recently concluded that no strong stance is practical and have begun to search for ways of eliding the contraries that frame the debate. For an appreciation of how some historians have attempted to transcend stereotypical confrontations between technological determinism (materialistic determinism) and social constructionism (idealistic voluntarism), consider briefly two papers recently published in the collection of Smith and Marx (1994), Does Technology Drive History: The Dilemma of Technological Determinism.

In ‘Retrieving Sociotechnical Change from Technological Determinism’, Thomas Misa notes that technological determinists and social constructionists typically draw on evidence from different levels of analysis to construct their arguments:

... machines make history when historians and other analysts adopt a ‘macro’ perspective, whereas a causal role for the machine is not present and is not possible for analysts who adopt a ‘micro’ perspective... Besides taking a larger unit of analysis, macro studies tend to abstract from individual cases, to impute rationality on actors’ behalfs or posit functionality for their actions... Accounts focusing on these ‘order bestowing principles’ lead toward technological, economic or ecological determinism. Conversely, accounts focusing on historical contingency and variety of experience lead away from all determinism. Besides taking a smaller unit of analysis, such micro studies tend to focus solely on case
studies, to refute rationality or confute functionality, and to be disorder-respecting (Misa, 1994, pp. 117-119).

Misa argues that resolving dilemmas of determinism and materialism by privileging one level of analysis over another is not only empirically dissatisfying, it allows analysts to sidestep important issues. Scholars who champion voluntarism and idealism by insisting on micro-level data are "forced to omit comment on the intriguing question of whether technology has any influence on anything" (p. 138). The claim that technology exerts no socially significant material force on the direction of society is not only inconsistent with everyday experience, but as Misa notes, it "seems especially undesirable in an age of pervasive socio-technical problems." (p. 138) Social constructionists, therefore, risk assigning technology too little role in making history. Technological determinists, on the other hand, either risk creating the image of an autonomous social process that lies beyond human awareness or imputing motives and intentions without the warrant of evidence. Thus, the worldview of a determinist (whether materialistic or idealistic) too easily reduces humans to cultural and social dupes. Misa argues that a more plausible stance lies in the middle ground between determinism and voluntarism, where constraints and affordances both exist. This middle ground, which Misa calls the 'meso level', is populated by institutional actors:

For historians of technology and business this means analyzing the institutions intermediate between the firm and the market or between the individual and the state. A short list of these might include manufacturers' organizations (including cartels and interfirm networks), standard setting bodies (including the engineering profession and public agencies), export-import firms specializing in technology transfer, consulting engineering firms and investment banking houses. Since these institutions mediate between key actors in society, whether they orchestrate or respond to sociotechnical change, such an analysis would naturally lead us to the historical public debates concerning the costs and benefits of sociotechnical change.

Institutions are critical in Misa's view because they represent social mechanisms by which one group's volition can be translated into another group's constraint.

Hughes (1994) offers an alternate approach to bridging the philosophical chasm between determinism and voluntarism and between materialism and idealism. Rather than speak of specific technologies, Hughes posits the notion of a 'technological system.' By technological system, Hughes means to denote a complex of cultural, organizational and technological phenomena jointly focused on a particular productive or political goal: for instance, the system for generating, distributing and using electricity or the system surrounding the production and use of automobiles. As in Misa's resolution, organizations, professions and other institutions play crucial roles in building and sustaining technological systems. The image is similar to Dimaggio's interpretation of an 'organizational field' (DiMaggio, 1988). Hughes argues that human choices and ideologies matter a great deal in the early life of such systems when they are being constructed by individuals with specific ideas or agendas. However, Hughes contends that as such systems grow they become institutionalized, they take on a life of their own,
so that they begin to act more like material determinants of social reality. Hughes refers to the accretion of materialistic and deterministic force as technological momentum:

A technological system can be both a cause and an effect: it can shape or be shaped by society. As they grow larger and more complex, systems tend to be more shaping of society and less shaped by it. Therefore, the momentum of technological systems is a concept that can be located somewhere between the poles of technological determinism and social constructivism. The social constructivists have a key to understanding the behavior of young systems; technological determinists come into their own with the mature ones. Technological momentum, however, provides a more flexible mode of interpretation and one that is in accord with the history of large systems. (Hughes, 1994, p. 112)

Whether one deems Misa’s or Hughes’ approach to the dilemmas of materialism vs. idealism and determinism vs. voluntarism convincing is, for the purpose of this essay, irrelevant. More important is that Misa and Hughes have wrestled with crucial questions that are just beginning to filter into the management of technology. Although the MOT literature traditionally paid little attention to issues of determinism and materialism, over the last decade the field’s epistemological calm has been breached by advocates of social construction. Although the breach is positive, it seems likely that the emergence of these alternative visions could lead to the type of polarized debate that has already occurred in the history (and the sociology) of technology. Students of the management of technology might be able to avert such polarization by attending to historians who have already explored these issues in considerable depth and who have begun to search for ways of eliding them. Transcending these contraries is likely to be more generative, both theoretically and empirically, than simply recapitulating arguments for the superiority of one stance or the other, a debate that historians have already shown cannot be won.

4. Conclusion

Because MOT is a field whose advice is of considerable interest to policy makers, those of us who study the management of technology can hope to influence practices and understandings of technological change in ways that historians of technology (and, for that matter, most other social scientists) cannot. Compared to historians, students of MOT are far more likely to have access to the people who design, produce, implement and manage the technologies that affect our lives. Decision makers actually seek our advice and sometimes read our literature. Thus, we not only stand to profit intellectually from scholarly encounters with the history of technology, we are in a position to disseminate more widely the wisdom that historians have amassed in their encounters with the technologies and technological changes of the past.

By learning to typify the atypical, connect discontinuities, and transcend contraries, students of the management of technology may become a bit more circumspect and, hence, less likely than those we sometimes serve to fall victim to the seduction of technological promise and novelty. Because issues of technological change and policy
have serious implications for the future, scholars of the management of technology have an obligation to neither replicate nor reinforce the blindspots that affect our culture at large. As we go about our business of helping others understand today and invent tomorrow, it behooves us to keep an eye firmly fixed on yesterday. Harry Truman once said, "There is nothing new in the world except the history you don’t know" (quoted in Hillman, 1952). Beneath Truman’s hyperbole lies a kernel of truth.

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