Standardization in History: A Review Essay with an Eye to the Future

ANDREW L. RUSSELL

Department of the History of Science and Technology, The Johns Hopkins University

Abstract: *This article presents an overview of recent work by historians on standards and standardization. Historical research can be useful for informing policymakers and strategists about specific aspects of the standards process; it may also provoke reflections on long-term trends or neglected aspects of standardization. In the first section, the historical literature is analyzed under five themes: politics, business & economics, science & technology, labor, and culture & ideas. These five themes provide structure for speculations in the second section about some of the salient issues that will face both the engineers who create future generations of standards as well as the future historians who will analyze their efforts.*

Introduction

> History is the witness that testifies to the passing of time; it illuminates reality, vitalizes memory, provides guidance in daily life, and brings us tidings of antiquity.
>
> \- Marcus Tullius Cicero

The recent surge of academic interest in standardization is not limited to students of business, economics, and engineering. Over the past fifteen years, a steady increase in research by historians examines standardization for examples of cooperation and competition in human affairs. In a broad sense, standardization is the process of articulating and implementing technical knowledge. Standards can emerge as the consequence of consensus, the imposition of authority, or a combination of both. Since this process contains many different facets, historians have found that standardization provides plenty of material to address some major historical issues.

This article—necessarily illustrative instead of comprehensive—is organized around two questions. First, what do historians write about when they address standards and standardization? Second, what questions might future historians pose as they evaluate future generations of standards? A brief survey of existing historical literature on standards and standardization will provide answers to the first question. This survey of standardization past and present will, in turn, lay the groundwork for some of the big questions that will confront those who create—and analyze—future generations of standards.

Past Generations

One of the reasons standardization is so compelling for historians and social scientists is its multidisciplinary characteristics: politics, business & economics, science & technology, labor, and culture & ideas are inextricably linked through standardization. The existing historical literature on standards and standardization touches each of these distinct realms. This literature also demonstrates how a multidisciplinary approach that combines insights from all of these realms facilitates a richer understanding of standards and standardization.

Of course, the specific meaning of the term "standard" varies depending on context: it can refer to a screw thread, a unit of measurement, a regular set of practices, or a way of looking at the world. At first, this variety may be confusing for those who appreciate precision terminology. However, I hope to show that a broad view of standards in history—one that is not restricted to information and communications technology (ICT) standards—will help present and future generations to recognize old and new patterns. Indeed, this historical variety demonstrates the breadth and enduring importance of the concepts of standards and standardization.

Politics

For over two thousand years, governments have presided over the creation of standards.[1] Governments also used their authority to enforce the use of standards. Through this involvement, rulers and regulators sought to enhance their own prestige and power, while simultaneously seeking to improve their own economic fortunes and those of their constituents.

One striking example of this phenomenon can be seen in the creation of standards for telegraphy in Victorian Britain. As Bruce Hunt argues, the commercial and practical demands of British imperialism directly shaped research in cable telegraphy—a "quintessential technology of empire"—in nineteenth-century Britain.[2] Since British officials were dependent on a global cable network for imperial control, their best physicists—including James Clerk Maxwell and William Thomson (named Lord Kelvin in 1891)—led studies of the propagation of signals through underwater cables in order to bring a higher level of precision to cable manufacturing and testing. Through these theoretical and practical efforts, British physicists articulated a standard level of electrical resistance still in use today—the ohm.[3] Although many other measures of resistance existed at the time (including one developed by the German physicist Werner Siemens), the ohm specified in 1865 by the British Association for the Advancement of Science became a global *de facto* standard due to the advanced state of British telegraphy—the "nerves of empire"—and British domination of the global telegraphy industry.[4]

Political concerns also drove the efforts to create another fundamental standard that has faded into the background of everyday life: the meter. In his dramatic account of the origins of the meter in late eighteenth-century France, Ken Alder details the change from a confounding diversity of weights and measures under the French Monarchy—up to 250,000 different units of weights and measures across the provinces and towns of France—to the creation, after the French Revolution, of a more rational system. Where the old system inhibited efficient state administration and inter-regional commerce, the new system was touted as a way to erase the arbitrary nature of local rule. According to Condorcet—a leading scientist and "history's great optimist for human progress"—the new system would "ensure that in the future all citizens will be self-reliant in all those calculations which bear upon their own interests; because without this independence citizens can neither be equal in rights…, nor truly free…"[5] In short, new rational standards were an essential part of the Revolution that sought to establish political liberty and equality.

Nations began to create institutions for standards research and development in the late nineteenth and early twentieth century. In Germany, the Physikalisch-Technische Reichsanstalt (German Imperial Institute of Physics and Technology) was founded in 1887 to perform scientific research, set electrical standards, and coordinate innovation in science-based industries—all of which contributed to the vitality of industry in the German Empire.[6] The success of the Reichsanstalt soon encouraged institutional imitators abroad, including the British National Physical Laboratory (founded in 1899) and the American National Bureau of Standards (NBS). The NBS was created in 1901 by an act of Congress to coordinate the rapid proliferation of scientific standards as well as to carry out scientific research in its own laboratories. At first, the NBS focused its efforts narrowly on standards for weights, measures, heat, and optics; but it soon expanded its mission to include electricity research as well as testing of materials and products for various government agencies.[7]

After World War I, Commerce Secretary Herbert Hoover became a champion for standardization as a method for preventing "waste in industry."[8] Hoover's vision of an "associative state" called for government agencies (like NBS) to work with cooperative institutions in order to capture the benefits of engineering and rationalization while also fostering "American Individualism."[9] Hoover's efforts to use government as a catalyst for cooperation have been obscured by the 1929 market crash and subsequent Depression. Despite Hoover's misfortune as president, his broader vision of cooperation between public and private sectors has proven to be a recurrent theme, both in American politics as well as in the standardization activities that occur at the boundaries between the federal government and private industry.[10]

Business & Economics

Readers who are familiar with previous volumes in *The Standards Edge* series will understand the central importance of standards for business and economics. In broad terms, standards can create intra-firm and inter-firm efficiencies: they facilitate economies of scale in manufacturing and promote interoperability between complementary products. These economics are especially clear in telecommunications networks. In the past, monopoly firms were responsible for telecommunication networks; standards were consequently the responsibility of managers within that single firm. After global reforms during the 1980s and 1990s privatized telecom networks and opened them to competition, ICT networks became more *modular* in character. In this post-monopoly era, inter-firm relationships (such as standards-setting committees) provide the technical and organizational coordination mechanisms that used to be the domain of monopoly firms.[11]

The foundational historical works that describe the beginnings of standardization into American manufacturing are books by David Hounshell and Merritt Roe Smith. Hounshell and Smith describe the introduction of interchangeable parts into American armories at Harpers Ferry and Springfield in the early nineteenth century. Inspired by ideas used in French armories in the 1780s—and motivated by the military needs of the American Ordnance Department in the early 1800s—managers at Harpers Ferry and Springfield introduced equipment and techniques to manufacture interchangeable parts for muskets and to inspect and test the parts to ensure uniformity. Standardization practices spread throughout American industry as mechanics brought their armory experiences and techniques with them into other factories and industries such as machine tools, sewing machines, bicycles, and eventually automobiles.[12]

Standards and standardization also were vital to innovation and industry development in a major network industry of the late nineteenth and early twentieth century: the railroads. In *Regulating Railroad Innovation*, Steven Usselman shows how the standardization of steel rails, "double-acting" brakes, and numerous other innovations enhanced the efficiency, safety, and comfort of railroad transportation. As they developed and implemented these technical innovations, the railroads also pursued organizational innovations that enabled them to control the growth of the industry and technological change itself. Readers familiar with the "patent thicket" of the present day may find it particularly interesting to reflect on the discussion in chapter 4 ("Patent Remedies: Politics, Jurisprudence, and Procedure"). There, Usselman describes how the railroads, frustrated by the chaos and unpredictability of the market-based system for patents, circumvented that system by creating trade associations and engineering societies to facilitate the industry-wide exchange of technical standards.[13]

Railroad companies were not alone in forming industry groups in the late nineteenth century. Many engineering associations emerged during this period to create industry-wide approaches to technical standards (as well as professional education for engineers, public dissemination of technical information and expert advice, and uniformity in nomenclature, testing, quality specifications, and safety rules).[14] It is important to consider these associations within the broader context of the "search for order" in early twentieth-century America: they are examples of cooperative initiatives in an age of "progressive" reform that tried to come to grips with the chaos and irrationality of an increasingly complex world.[15] Historical accounts of the nascent engineering associations reveal dedicated efforts by engineers to establish industry consensus for standards, as well as significant resistance from firms that did not want to incur the costs of standardization or were suspicious of the competitive implications. In response to the wartime rationale for industry standardization, the "big five" engineering societies joined with the U. S. Departments of Commerce, Navy, and War in 1918 to found the American Engineering Standards Committee. By 1928, this group had reorganized and renamed itself the American Standards Association (ASA). The ASA and National Bureau of Standards both cooperated and overlapped in many areas, and jurisdictional conflicts were common. The core philosophical issue behind these conflicts—whether industry standards should be promulgated from a government body or, instead, emerge from a voluntary consensus process—suggest that tensions between *de jure* and *de facto* standards have been present at least since the early twentieth century.[16]

American telecommunications standards were developed during the same time, but under quite different organizational conditions. For much of the twentieth century, the history of American telecommunications is indistinguishable from the history of the Bell System. AT&T's emergence as a national monopoly was based on strategies for horizontal and vertical integration that depended to a large degree on standards. Bell engineers established and maintained the efficiency and quality of their entire system by deploying standardized equipment throughout it; these standards also provided a rationale for refusing to interconnect with independent companies that used inferior standards.[17] AT&T also used standards to create efficiencies on the supply side, notably in their integration with the so-called "manufacturing department of the Bell System," Western Electric.[18] This model of horizontal and vertical integration helped to make AT&T the leader in global telecommunications and—with over 1 million employees by the 1970s—the largest company in the world.

Many standards in late twentieth-century ICT networks deeply influence business and economics, but have their roots in non-commercial organizations. Most readers will be familiar with Janet Abbate's *Inventing the Internet*, which tells the complex story of how non-proprietary Internet standards emerged from a distinctly Cold War-era mix of academic and defense research.[19] In contrast to proprietary networking products developed by IBM and Digital, Internet standards (such as TCP/IP) were implemented widely during the 1980s and early 1990s thanks to their flexibility and low cost. Additionally, the organizations responsible for setting Internet standards—including the Internet Architecture Board and the Internet Engineering Task Force—were more nimble and responsive to the "bottom-up" concerns of developers than the steward of a competing "open systems" architecture, the International Organization for Standardization (ISO).[20]

Another notable book-length history of recent information technology standardization is Urs von Burg's *The Triumph of Ethernet*. This study is particularly useful because it follows the development of competing LAN standards from their creation and specification in committees through their implementation in industry. Von Burg grounds his analysis around his concept of "technological communities," which he defines as including "all those firms, organizations, and individuals that are directly or indirectly involved in the development, manufacturing, and distribution of a particular technology or standard."[21] Readers who need to anticipate the future course of other open standards (such as those in the IEEE 802 family) will benefit from a careful consideration of von Burg's discussion of innovation, competition, and consensus.

Science & Technology

Standardization is a fundamentally technical enterprise, the result of scientific and technological activity. The main scientific function of standardization—the collaborative production and dissemination of technical knowledge—is a compelling theme for historians of science and technology. By looking more closely at the scientific process, we can gain a better appreciation for the messiness and complexity that scientists need to overcome in order to create results that appear objective and reliable.

Many historians of science and technology look to standards as examples of the codification of scientific knowledge and expertise. The examples of the ohm and the meter (see above) are two good examples of viewing standardization as a *process* that, if successful, creates a standard that is both authoritative and trusted. In many cases, the production of trusted knowledge occurs through the use of precision instruments. Galileo's use of telescopes and Lavoisier's use of balances and calorimeters are classic examples of instruments that were used as part of broader strategies for gaining trust.[22]

In addition to the need to use precise laboratory instruments, scientists have also used standardized organisms to produce scientific knowledge. Many significant scientific advances depended upon standardized organisms: perhaps the best example is *drosophila*, the fruit fly that T.H. Morgan and others began using in the early 1900s for breeding experiments that measured adaptation and variation. The standardized *drosophila* has been at the heart of fundamental advances in genetics, from the first proof that genes exist on chromosomes (1916) to the first organism to have its genome fully sequenced (2000).[23] Similar to industrial production, the use of standards in the production of scientific knowledge pushed scientists to reform the human relationships their laboratories. Robert Kohler's study of Morgan's "fly people," together with Dan Todes's work on the Russian physiologist Ivan Pavlov, show how scientists experimented with organizational forms alongside their efforts to create scientific knowledge from experiments with standardized laboratory organisms.[24]

While much of this literature does not address the specific conditions of ICT standardization, it does illuminate some of the challenges inherent in efforts to forge scientific and technological consensus. Moreover, the history of precision and standardization in scientific research is important because it was foundational for subsequent industrial development. Especially in science-based industries that relied on engineers with expertise in chemistry, electricity, and physics, it is difficult to argue with David Noble's observation that "scientific standardization paved the way for industrial standardization."[25]

Labor

The extensive literature on the economics of standards tends to overlook the extent to which the creation and implementation of standards requires tremendous amounts of human labor. Several recent studies illustrate how different types of workers are required to put standards into practice. In addition to the work that people do to create and implement standards, managers and executives have used increasingly sophisticated techniques to standardize and rationalize practices in the workplace. This section will treat these two topics—standards labor and labor standards, if you will—in turn.

As noted above, the professionalization of engineering in the nineteenth and twentieth centuries provided venues for industry standardization activities. If an engineer wanted to be considered "professional," he or she needed to become a member of a professional society (such as the ASCE or ASME). The growth of these societies was contentious and had a marked influence on the boundaries of acceptable professional engineering practice. As A. Michal McMahon documents in his history of IEEE, some of the central problems of professionalization included the group's stance toward "pure" scientific and "applied" industrial engineering, membership criteria, and educational and ethical standards. In response to rapid growth after World War II, the creation and constant development of a hierarchical and multidivisional committee structure helped keep the organization flexible and able to stay focused on standardization activities across a variety of technical areas. The history of this and other engineering societies make it clear that the establishment of technical standards occurred within the broader context of engineers struggling to define their profession.[26]

Standards also changed the value of expert labor in the twentieth century. In an insightful essay, Amy Slaton and Janet Abbate argue that standards redistribute responsibility for manual and intellectual labor among "groups of workers, between industry sectors, or between producers and consumers. If we look at the larger system of specifying, producing, marketing, and using goods and services, we can see that the adoption of standards may simplify some aspects of the system while creating a demand for more skilled labor elsewhere."[27] For example, the standardization and mass-production of prefabricated staircases, chimneys, sheds, and warehouses meant that skilled laborers such as carpenters, masons, roofers, and painters became less valuable in the construction industry by the 1930s. With standard materials, construction firms could hire cheaper, unskilled workers in the place of skilled tradesmen.

Historians celebrate a small group of engineers and computer scientists (such as Vint Cerf, Robert Kahn, and Jon Postel) for creating Internet standards; but the implementation of these standards required labor from a much bigger group of people. For example, the Arpanet's host protocol transition from NCP to TCP in 1983 left a strong impression in the memories of many community members responsible for implementing TCP. Tangible artifacts remain from what Slaton and Abbate describe as a "traumatic and disruptive experience": buttons that proclaim, "I Survived the TCP Transition."[28] Readers who dealt directly with Y2K compatibility problems will be sympathetic.

Greg Downey's recent work challenges us to think about unskilled and non-professional labor in the standardization process. In his book *Telegraph Messenger Boys*, Downey skillfully shows that the end-to-end transmission of messages across telegraph networks relied not only on the technological network of wires and signals, but also on a human network of boys who would deliver telegrams from central stations to the homes of customers. Like Slaton and Abbate, Downey reminds us that the creation of standards by a small group is only one part of the system-building process. Applied to Internet standardization, Downey's concept of "protocol labor" pushes us to remember that we should not neglect the implementation and constant maintenance of standards required at the edges of the network. Downey's concern is not in a "priority dispute" of who invented Internet standards, but, instead, "Who is operating the Internet?" and "Where is that operation taking place?"[29]

In historical terms, standardization in industry went hand-in-hand with the standardization of workplace procedures. Frederick W. Taylor's *Principles of Scientific Management* (published in 1911), famous for its time and motion studies of factory workers, became influential in industry at the exact same time as mass production with interchangeable standard parts. David Hounshell cautions that "Taylorism" and "Fordism" should not be conflated: where Taylor promoted efficiency in human movements, Henry Ford promoted the use of machinery for factory mass production.[30] Despite these differences, both Taylorism and Fordism are significant because they represented fundamental advances in the human and technological aspects of standardization in factory production: further evidence that standardization in science, industry, and labor are deeply interrelated both in theory and in practice. As the Dean of Engineering at Cornell University (and manager for General Electric) noted in 1929: "the extension of the principles of standardization to the human element in production is a most important and growing field of inquiry."[31]

Culture & Ideas

Standardization—a powerful concept in its own right—has, throughout history, been associated with many other influential ideas. Like labor historians, cultural and intellectual historians provide insights that tend to be overlooked by students of business, economics, and engineering. When writing about standardization, cultural and intellectual historians bring human interactions to life by showing how a variety of values and choices permeate the history of what appears on the surface to be a dry and technical subject.

As discussed above, such luminaries as Condorcet envisioned the standardization of weights and measures as an essential component of the French Revolution that would herald a new age of Enlightenment, rationalization, freedom, and equality in late eighteenth-century France. In order to establish an objective basis for the meter—defined as one ten-millionth of the distance from the North Pole to the equator—the French Academy of Sciences chose two distinguished scientists to measure the size of the earth. For one of these men, the pursuit of this measurement was "a moral quest as much as a scientific one… Its consummation proved that the investigator possessed the patience, skill, and rectitude to reveal nature's predictability and lawfulness."[32]

Descriptions of standardization and precision measurement as *moral* concerns echo throughout the nineteenth century: as Theodore M. Porter noted in his study of actuaries in Victorian Britain, "exact measurement began very early to mean intense discipline tending to self-effacement."[33] This rigorous quantitative practice helped to instill important "moral virtues of responsibility, logical consistency, and due caution."[34] In his 1900 Senate testimony advocating the establishment of the National Bureau of Standards, Treasury Secretary Lyman Gage acknowledged a "moral aspect" of "absolutely correct scientific standards" that could help to counter the "looseness" in methods and ideas that he saw as the results from rapid development.[35]

These moral aspects of standardization not only persisted into the twentieth century; they formed the ethical bedrock for emerging engineering professions. As noted above, the professionalization of engineering entailed the creation of committees for setting technical standards, as well as the standardization of engineering education, terminology, and practices. In his classic book *The Revolt of the Engineers*, Edwin T. Layton, Jr. reminds us that professional autonomy and ethics—especially social responsibility—were critical components of the engineering professions during the early twentieth century.[36] In the first decades of the twentieth century, the engineer and reformer Morris L. Cooke thought that engineers could be the vanguard of Utopian salvation if they would recognize that public interests—as opposed to corporate interests—should be the true beneficiaries of the engineering profession. Subsequent engineers—less radical than Cooke—accepted that their labors would be essential for public safety. Indeed, the unwanted attention that engineers and standards receive in the wake of disasters underlines the extent to which modern life depends on the safety, consistency, and precision of standardization and engineering practice.[37]

Beyond these social and ideological intersections between standardization, professionalization, and progressive reform, plenty of evidence exists to illustrate some connections between the ideas of standardization, rationality, and a meaningful life. For the French Revolutionaries, standardization was part of an enlightenment project: rational minds needed rational measures. One group in the new French Republic argued that regular weights and measures served a pedagogical function: "Even the least practiced minds will acquire a taste for this order once they come to know it."[38]

By the twentieth century this spirit of rationality existed within new contexts that, while celebrated in industry (by reformer-engineers such as Taylor and Hoover), were the subject of harsh criticism. Just as Karl Marx attacked the rationality and routinization of nineteenth-century industrial capitalism, so too did twentieth-century critics find the monotony and uniformity of "the standardised life" to be detrimental to human autonomy. The Fabian Socialist William Robson, while celebrating the benefits that industrial standardization had brought to modern life, was deeply critical of the extension of the logic of standardization beyond the economic realm. If standardization was extended to leisure activities or non-economic pursuits, Robson warned, "we should merely have used our increased wealth to purchase slavery."[39] For Robson, the most pressing concern was not whether standardization itself was good or bad; the real question for the community was "to what extent, in what measure, how, why, and when it should resist or promote measures tending toward uniformity."[40] Aldous Huxley expressed a similar concern in his chilling 1932 classic *Brave New World*: "standard men and women" are the disturbing centerpieces of his story, the result of "the principle of mass production at last applied to biology."[41]

In each of these examples, we see a tension between autonomy and control. Paul David—author of several seminal contributions to the economics and history of standards—takes up this theme in a brilliant essay.[42] David's essay, while geared toward economic policy, speaks to the more abstract issues that underlie the history of standardization. "The kernel of the problem," David writes, "may be construed to be nothing more and nothing less than the fundamental issue with which all social organizations are confronted: where to position themselves on the terrain between the poles of 'order' and 'freedom.'" After weighing the benefits and costs of these polar opposites, David concludes that the tradeoffs are too complex, with too much contextual nuance, to advocate a single "best form" of standardization. Instead, his sensible prescription favors balance and continued flexibility "in the space between the poles of authoritarian regimentation and anarchic freedom."[43]

Present and Future Generations

Taken together, the scholarship discussed above demonstrates how standards and standardization touch many diverse aspects of human activity, from political revolutions to commercial rivalries, from *drosophila* research to literary dystopias. What can this research tell us about trends in ICT standardization that future generations will encounter? And what questions might future historians pose as they try to make sense of present and future generations of standards?

These questions, of course, are impossible to answer fully. Accordingly, the sections below contain more questions than answers. One general observation is that the boundaries between these distinct realms—for example, between politics and economics—will continue to blur. In this section and in the conclusion, I will reflect on two of the most prominent drivers of this blurring: globalization and convergence. (I should note that the remainder of the article assumes an American perspective; a comparative view of the future landscape from other national perspectives would be most rewarding and enriching.)

Politics

The perennial question—what should be the role of government in the standardization process?—is too broadly crafted to permit an authoritative or convincing answer. A different way to pose the question is, when will standards emerge as the result of bottom-up consensus, and when will they be accelerated through top-down authority? Present U. S. policies for government production and procurement of standards—as articulated in ANSI's U. S. National Standards Strategy and OMB Circular A-119—emphasize the virtues of the voluntary consensus standardization process.[44] These policy guidelines also permit a good deal of flexibility for regulators. If history is any guide, regulators are most likely to participate actively in the standards process if they are acting on the basis of scarcity, interference, and/or public safety rationales.

More aggressive regulators and policymakers may see fit to get involved in standardization in order to meet objectives specified by industrial or innovation policy. While there seems to be, in broad terms, a global trend away from this sort of proactive standardization, the recent historical record reveals deeply conflicting results. For example, the European Union's active involvement in the creation of the GSM standard for mobile telephone networks created tremendous short-term successes for European political and economic integration, as well as significant first-mover advantages for European firms in global markets.[45] In some cases, however, there may be significant, unforeseen costs of being "locked in" to anticipatory standards.[46] Additionally, as the lethargic transitions to HDTV television networks and an IPv6 Internet demonstrate, government mandates may be ineffective (or simply beside the point) if markets and consumers are not willing to adopt new standards. Future studies of transitions to new generations of ICT networks will compare various approaches by different national, regional, and global governing bodies; hopefully these studies will reveal new lessons about the causes of short-term and long-term success and failure.

Business & Economics

Future historians will be keen to study success and failure in new organizational forms. To better understand some characteristics of ICT industries, we may find fruitful comparisons in non-ICT industries, such as transportation, public utilities, biomedical research, or health care.[47] What organizational forms—such as *ad hoc* alliances, formal standards-setting organizations, or informal consortia—will be able to attract stakeholders and sustain future networks? For ICT networks, Bell System-style monopoly strategies of horizontal and vertical integration are no longer possible in today's post-monopoly environment populated by multiple firms, multiple networks, and a dizzying array of technical standards. Will voluntary consensus bodies—such as the Internet Engineering Task Force—be able to withstand increasing commercial pressures (on the one hand) and calls for more formal structures and international participation (on the other)? Or will they sputter into irrelevance in the face of new organizational competitors?

These organizational questions are closely related to strategies for using and sharing patents and intellectual property rights (IPRs). How should firms choose between multiple venues for standardization? Which institutions work well, which do not, and why? In the layered Internet model, will IPR strategies at the network level continue to differ from IPR strategies at the application and content levels? Will an IPR strategy that is effective in the United States be effective (or legal) in Europe or Asia?[48]

Science & Technology

Just as the packet-switched Internet took the legacy telecommunications world by surprise, it is not inconceivable that unanticipated technologies will alter the development of our present ICT networks. The great unknowable question, of course, is where will the new technologies come from? What will they look like?

Since the decisive worldwide movement in the 1980s and 1990s toward the privatization of telecommunications, funding mechanisms for high-tech research and development have been in flux. Since we are no longer in an era where the research labs of monopoly firms (such as Bell Labs) are insulated from market pressures, many observers wonder if corporate innovation policies are too shortsighted to produce significant breakthrough innovations. Government and/or military funding may provide autonomy for scientists to engage in foundational basic research, as may closer relationships between universities and private firms.[49] But will pressure from these funding sources distort the paths of scientific research, as they did during the Cold War?[50] Will researchers be discouraged from pursuing intellectually interesting projects that have no apparent short-term marketable applications? Or will the model of large, multipurpose industrial labs give way to a structure where research and innovation is distributed over multiple firms around the globe? The development of the Internet and the GSM standard suggest that many firms can coordinate modular innovations by negotiating interfaces and patent rights in committees and market transactions. But, in this model of decentralized innovation, will the absence of a "master architect" hinder the coordination of future network architectures?[51]

As in the past, technical expertise remains essential for the creation of high-quality standards. Talented young people may not immediately be attracted to a career that involves the development of new standards. In higher education, Engineering and Computer Science departments should continue to develop curricula geared towards producing graduates with the skills required for participating in the standardization process.[52]

Labor

As we continue to experiment with different organizations for setting standards, some broader questions relating to "protocol labor" will continue to emerge: is there such a thing as a standards professional? What do engineers learn from their experiences in standards committees, and how do they apply that knowledge in new settings?

Moreover, who—beyond the engineers who participate in standards committees—are today's "protocol laborers"? As Downey asked, who is operating the Internet, and where does that operation take place? In the golden age of the Bell System, users only needed to know how to pick up and dial a phone. To use today's telecommunication and information networks, users must be significantly more sophisticated: the hornet's nest of router configuration, firewall and virus management, home networking, and peripheral coordination is the price that users pay in exchange for modular, post-monopoly ICT markets. Will users learn how to configure these systems themselves? Or will the market for "bundled" services that manage this complexity continue to grow?

Further, how will "outsourcing" affect the skills and expertise of workers around the globe? Who will benefit from this seemingly inexorable global redistribution of labor? Will the tasks of information workers be standardized in cubicle farms and sanitized call centers, or will an increase in telecommuting liberate workers from twentieth-century offices and enable them to work from home or from "virtual offices" around the globe?

Culture & Ideas

The tension between the ideals of open and proprietary standards looms over future generations of standards. While many of the core tenets of open standards—open participation, consensus, due process, and full IPR disclosure—are admired widely, many firms have found that strict adherence to these principles may have high competitive costs. How will the similarities and differences between open standards and open source software influence future generations of standards?[53]

As we navigate the spaces between freedom and order, how will users and consumers be able to influence the standardization process?[54] A community of researchers growing around the notion of "values in design" seeks to show how values such as privacy, security, autonomy, and social justice influence the design process.[55] What assumptions will be embedded in future generations of standards? Should we take those assumptions to be "natural" and inevitable, or, instead, try to understand how they are influenced by the broader social and cultural currents of the early twenty-first century? If the ideas, values, and assumptions of standardization and precision changed between the late eighteenth-century age of Revolution and Enlightenment and the late twentieth-century Cold War, shouldn't we also expect these ideas, values, and assumptions to change in a new era of post-Cold War globalization? Will the "average person" think of standards as the vanguard of liberty, or as the tools of authoritarian order?

Conclusion

The implicit argument in this article is that distinctions between categories such as politics, economics, technology, and labor can be useful for focusing on specific aspects of the standardization process. But the lesson is not to get stuck in these distinctions; rather, it is that we should appreciate these distinctions as components of bigger questions that will confront future generations as they carry forward with the detailed and specific work in the particular tasks of regulation, corporate strategy, and technical innovation. In other words, a comprehensive approach to standardization should integrate perspectives from each of these five realms.

Future generations will find that globalization and convergence are more than buzzwords. Globalization—for our purposes, the movement of goods, services, and ideas across national boundaries—and international travel have been basic facts of ICT standardization for over a century.[56] For a while, technologies such as the Internet seemed to defy the abilities of national governments to control them. This situation is changing rapidly, and the people who create and implement standards will be subject to increased scrutiny from policymakers and regulators. It also bears repeating that this situation looks different from a non-American perspective.

Anyone who orders telephone service from his or her cable TV company understands that technological convergence is an inescapable fact of life.[57] As lawyers and regulators struggle to adapt to the new realities of convergence, will we see a convergence of standards-setting organizations as well? Or will we instead see movement in the opposite direction in the shape of a proliferation of consortia and *ad hoc* alliances that are narrowly focused and able to move very quickly?

While the details of future generations remain to be seen, the basic challenges that face future generations of standards architects and engineers will be similar to challenges of the past: What will be the role of government? How much cooperation will be necessary to facilitate competition? Who will generate new technical knowledge? What will be the implications for the workers who create and implement standards? How will future generations of standards reflect existing ideas and cultural assumptions, and how will they catalyze new ones?

In some cases, people who will make decisions about future generations of standards can learn directly applicable lessons by studying the experiences of past generations. Beyond this instrumentalist view of the past, Cicero's words at the beginning point to a different role for history. This role is more restorative. Like most historians, I hesitate to try to predict the future. I can, however, make one prediction with virtual certainty: the architects and engineers of future generations of standards will inevitably confront headaches and sleepless nights. In this respect, they are not pioneers. The tales of success and failure throughout past generations of standards might help to console them. At the very least, these tales will bring them tidings of antiquity.

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Biography

Andrew Russell is a Ph.D. student in the Program in the History of Science, Medicine, and Technology at The Johns Hopkins University. He holds a B.A. in History from Vassar College and a M.A. in History from the University of Colorado at Boulder, where he studied American political, cultural and intellectual history, as well as telecommunications law, economics, and policy. Before attending graduate school, he worked for the Harvard Information Infrastructure Project in Harvard University's John F. Kennedy School of Government.

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[1] See J. G. Landels, *Engineering in the Ancient World* (London: Chatto and Windus, 1978); and John Perry, *The Story of Standards* (New York: Funk & Wagnalls Company, 1955).

[2] Bruce J. Hunt, "Doing Science in a Global Empire: Cable Telegraphy and Electrical Physics in Victorian Britain," in Bernard Lightman, ed., *Victorian Science in Context* (Chicago: The University of Chicago Press, 1997), 313.

[3] Bruce J. Hunt, "The Ohm Is Where the Art Is: British Telegraph Engineers and the Development of Electrical Standards," *Osiris* 9, 2nd Series, Instruments (1994): 48-63.

[4] Hunt, "Science in a Global Empire," 319.

[5] Ken Alder, *The Measure of All Things: The Seven-Year Odyssey and Hidden Error That Transformed the World* (New York: The Free Press, 2002), x; Marie-Jean-Antoine-Nicolas Caritat de Condorcet, quoted in Alder, *Measure of All Things*, 136.

[6] David Cahan, *An Institute for an Empire: the Physikalisch-Technische Reichsanstalt, 1871-1918* (New York: Cambridge University Press, 1989).

[7] Rexmond C. Cochrane, *Measures for Progress: A History of the National Bureau of Standards* (Washington, D.C.: U. S. Department of Commerce, 1966); James F. Schooley, *Responding to National Needs: The National Bureau of Standards Becomes the National Institute for Standards and Technology, 1969-1993* (Gaithersburg, MD: U. S. Department of Commerce, 2000). NBS was renamed as NIST in 1988.

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[9] Ellis W. Hawley, "Herbert Hoover, the Commerce Secretariat, and the Vision of an 'Associative State,' 1921-1928," *The Journal of American History* 61 (June, 1974): 116-140; Herbert Hoover, *American Individualism* (Garden City, NY: Doubleday, Page & Company, 1922); Herbert Hoover, "We Can Cooperate and Yet Compete," *Nation's Business*, 5 June, 1926.

[10] David M. Hart, "Herbert Hoover's Last Laugh: The Enduring Significance of the 'Associative State,'" *Journal of Policy History* 10 (1998): 419-444.

[11] Richard N. Langlois, "Modularity in Technology and Organization," *Journal of Economic Behavior and Organization* 49 (2002): 19-37; Stefano Brusoni and Andrea Prencipe, "Unpacking the Black Box of Modularity: Technologies, Products and Organizations," *Industrial and Corporate Change* 10 (2001): 179-205.

[12] David Hounshell, *From the American System to Mass Production, 1800-1932* (Baltimore: The Johns Hopkins University Press, 1984); Merritt Roe Smith, *Harpers Ferry Armory and the New Technology: The Challenge of Change* (Ithaca, N.Y.: Cornell University Press, 1977). For a critique of Smith and Hounshell that places a greater emphasis on techniques introduced by "profit maximizing entrepreneurs" (as opposed to federal armories), see Donald R. Hoke, *Ingenious Yankees: The Rise of the American System of Manufactures in the Private Sector* (New York: Columbia University Press, 1990).

[13] Steven W. Usselman, *Regulating Railroad Innovation: Business, Technology, and Politics in America, 1840-1920* (Cambridge: Cambridge University Press, 2002). On the use of different railroad track gauges, see George Rogers Taylor and Irene D. Neu, *The American Railroad Network, 1861-1890* (Cambridge: Harvard University Press, 1956), 58-66.

[14] The "big five" engineering associations in the late nineteenth century included the American Society of Civil Engineers (ASCE, founded 1852), the American Institute of Mining Engineers (AIME, 1871), the American Society of Mechanical Engineers (ASME, 1880), American Institute of Electrical Engineers (AIEE, 1884), and American Society for Testing Materials (ASTM, 1898). For an institutional history of one of these groups, see Bruce Sinclair, *A Centennial History of the American Society of Mechanical Engineers, 1880-1980* (Toronto: University of Toronto Press, 1980). See also Louis Galambos, *Competition & Cooperation: The Emergence of a National Trade Association* (Baltimore: The Johns Hopkins University Press, 1966).

[15] Robert H. Wiebe, *The Search for Order: 1877-1920* (New York: Hill and Wang, 1967); David F. Noble, *America By Design: Science, Technology, and the Rise of Corporate Capitalism* (New York: Oxford University Press, 1977).

[16] The ASA was renamed the American National Standards Institute (ANSI) in 1969.

[17] Robert W. Garnet, *The Telephone Enterprise: The Evolution of the Bell System's Horizontal Structure, 1876-1909* (Baltimore: The Johns Hopkins University Press, 1985); Milton Mueller, *Universal Service: Competition, Interconnection, and Monopoly in the Making of the American Telephone System* (Cambridge, MA: The MIT Press, 1997).

[18] George David Smith, *The Anatomy of a Business Strategy: Bell, Western Electric, and the Origins of the American Telephone Industry* (Baltimore: The Johns Hopkins University Press, 1985); Stephen B. Adams and Orville R. Butler, *Manufacturing the Future: A History of Western Electric* (New York: Cambridge University Press, 1999).

[19] Janet Abbate, *Inventing the Internet* (Cambridge, MA: The MIT Press, 1999). For an analysis of a contrasting approach to ICT standardization, see Susanne K. Schmidt and Raymund Werle, *Coordinating Technology: Studies in the International Standardization of Telecommunications* (Cambridge, MA: The MIT Press, 1998).

[20] See Andrew L. Russell, "'Rough Consensus and Running Code' and the Internet-OSI Standards War," forthcoming, 2005. Two entertaining contemporary accounts of this standards war are M. A. Padlipsky, *The Elements of Networking Style, And Other Animadversions on the Art of Intercomputer Networking* (Lincoln, NE: iUniverse, 2000, first edition Prentice-Hall, 1985); Carl Malamud, *Exploring the Internet: A Technical Travelogue* (Englewood Cliffs, NJ: PTR Prentice Hall, 1992).

[21] Urs von Burg, *The Triumph of Ethernet: Technological Communities and the Battle for the LAN Standard* (Stanford, CA: Stanford University Press, 2001), 25-46. For further discussion of recent examples that focus on strategic aspects of standardization and "standards wars," see Carl Shapiro and Hal Varian, *Information Rules: A Strategic Guide to the Network Economy* (Boston: Harvard Business School Press, 1999); and Peter Grindley, *Standards, Strategy, and Policy: Cases and Stories* (Oxford: Oxford University Press, 1995). For a foundational overview of the economic concepts, see Michael L. Katz and Carl Shapiro, "Systems Competition and Network Effects," *The Journal of Economic Perspectives* 8 (Spring, 1994): 93-115.

[22] Albert van Helden, "Telescopes and Authority from Galileo to Cassini," *Osiris* 9, 2nd Series, Instruments (1994): 9-29; and Jan Golinski, "'The Nicety of Experiment': Precision of Measurement and Precision of Reasoning in Late Eighteenth-Century Chemistry," in M. Norton Wise, ed., *The Values of Precision* (Princeton: Princeton University Press, 1995), 72-91.

[23] Robert E. Kohler, *Lords of the Fly: Drosophila Genetics and the Experimental Life* (Chicago: University of Chicago Press, 1994). See also Karen Rader, *Making Mice: Standardizing Animals for American Biomedical Research, 1900-1955* (Princeton: Princeton University Press, 2004).

[24] Daniel P. Todes, *Pavlov's Physiology Factory: Experiment, Interpretation, Laboratory Enterprise* (Baltimore: The Johns Hopkins University Press, 2002).

[25] Noble, *America By Design*, 76.

[26] A. Michal McMahon, *The Making of a Profession: A Century of Electrical Engineering in America* (New York: Institute of Electrical and Electronics Engineers, 1984). See also Andrew Abbott, *The*

System of Professions: An Essay on the Division of Expert Labor (Chicago: University of Chicago Press, 1988).

[27] Amy Slaton and Janet Abbate, "The Hidden Lives of Standards: Technical Prescriptions and the Transformation of Work in America," in Michael Thad Allen and Gabrielle Hecht, eds., *Technologies of Power: Essays in Honor of Thomas Parke Hughes and Agatha Chipley Hughes* (Cambridge, MA: The MIT Press, 2001), 96. See also Amy Slaton, *Reinforced Concrete and the Modernization of American Building, 1900-1930* (Baltimore: The Johns Hopkins University Press, 2001).

[28] Slaton and Abbate, "Hidden Lives of Standards," 127.

[29] Gregory J. Downey, *Telegraph Messenger Boys: Labor, Technology, and Geography, 1850-1950* (New York: Routledge, 2002); Gregory J. Downey, "Virtual Webs, Physical Technologies, and Hidden Workers: The Spaces of Labor in Information Internetworks," *Technology and Culture* 42 (April 2001): 236.

[30] Hounshell, *From the American System to Mass Production*, 249-254.

[31] Dexter S. Kimball, quoted in Noble, *America By Design*, 83. This statement is very similar to the sentiment expressed by Thomas Edison in 1920: "Problems in human engineering will receive during the coming years the same genius and attention which the nineteenth century gave to more material forms of engineering." Thomas Edison, quoted in Noble, *America By Design*, 257.

[32] Alder, *The Measure of All Things*, 60.

[33] Theodore M. Porter, "Precision and Trust: Early Victorian Insurance and the Politics of Calculation," in Wise, ed., *The Values of Precision*, 173.

[34] M. Norton Wise, "Precision: Agent of Unity and Product of Agreement Part II—The Age of Steam and Telegraphy," in Wise, ed., *The Values of Precision*, 227.

[35] Lyman Gage, quoted in Noble, *America By Design*, 74-5. On the moral and subjective aspects of materials testing before the advent of statistical quality control, see Slaton, *Reinforced Concrete*, 7-10, 20-61.

[36] Edwin T. Layton, Jr., *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession* (Baltimore: The Johns Hopkins University Press, 1986, first edition Press of Case Western University, 1971).

[37] Samuel Florman, *Blaming Technology: The Irrational Search for Scapegoats* (New York: St. Martin's Press, 1981), 105-119; Henry Petroski, *To Engineer is Human: The Role of Failure in Successful Design* (New York, St. Martin's Press, 1992).

[38] Agence Temporaire des Poids et Mesures, quoted in Alder, *The Measure of All Things*, 138.

[39] William Robson, *Socialism and the Standardised Life* (London: Fabian Society, 1926), Fabian Tract no. 219, 9.

[40] Robson, *Socialism and the Standardised Life*, 14.

[41] Aldous Huxley, *Brave New World* (New York: Perennial Classics, 1998, first edition Harper & Brothers, 1932), 7. George Orwell's *1984*, first published in 1949, is another strangely prescient dystopic vision of a homogenized future.

[42] Paul A. David, "Standardization Policies for Network Technologies: the Flux Between Freedom and Order Revisited," in Richard Hawkins, Robin Mansell, and Jim Skea, eds., *Standards, Innovation and Competitiveness: Politics and Economics of Standards in Natural and Technical Environments* (Aldershot: Edward Elgar, 1995), 15-35; see also Paul A. David, "Why Are Institutions the 'Carriers of History'?: Path Dependence and the Evolution of Conventions, Organizations, and Institutions," *Structural Change and Economic Dynamics* 5 (1994): 205-220.

[43] David, "Standardization Policies," 18, 35.

[44] Roger B. Marks and Robert E. Hebner, "Government/Industry Interactions in the Global Standards System," in Sherrie Bolin, ed., *The Standards Edge: Dynamic Tension* (Ann Arbor: Sheridan Books, 2004), 103-114; Carl Cargill, "The Role of Consortia Standards in Federal Government Procurements," in Sherrie Bolin, ed., *The Standards Edge* (Ann Arbor: Sheridan Books, 2002), 389-422.

[45] Jeffrey L. Funk, *Global Competition Between and Within Standards: The Case of Mobile Phones* (London: Palgrave, 2002).

[46] Shapiro and Varian, *Information Rules*, 103-134; Carl Cargill, "Evolution and Revolution in Open Systems," *StandardView* 2 (March 1994): 5.

[47] Naomi R. Lamoreaux, Daniel M. G. Raff, and Peter Temin, "Beyond Markets and Hierarchies: Toward a New Synthesis of American Business History," *American Historical Review* 108 (April 2003): 404-433; Louis Galambos with Jane Eliot Sewell, *Networks of Innovation: Vaccine Development at Merck, Sharp & Dohme, and Mulford, 1895-1995* (New York: Cambridge University Press, 1995); Stefan Timmermans and Marc Berg, *The Gold Standard: The Challenge of Evidence-Based Medicine and Standardization in Health Care* (Philadelphia: Temple University Press, 2003).

[48] Stephen Munden, "Strategic Standardization—Right Tool, Right Time, Right Job," in Bolin, ed., *Standards Edge: Dynamic Tension*, 189-198; Donald R. Deutsch, "Coordinating Oracle Participation in External Standards Setting Organizations," in Bolin, ed., *Standards Edge: Dynamic Tension*, 221-228; Andrew Updegrove, "Evaluating Whether to Join a Consortium," in Bolin, ed., *Standards Edge*, 129-138.

[49] Lewis M. Branscomb and Philip J. Auerswald, eds., *Taking Technical Risks: How Innovators, Managers, and Investors Manage Risk in High-Tech Innovations* (Cambridge, MA: The MIT Press, 2001); Lewis M. Branscomb and James H. Keller, eds., *Investing in Innovation: Creating a Research and Innovation Policy That Works* (Cambridge, MA: The MIT Press, 1998).

[50] Paul Forman, "Behind Quantum Electronics: National Security as Basis for Physical Research in the United States, 1940-1960," *Historical Studies in the Physical Sciences* 18 (1985): 149-229; Stuart W. Leslie, *The Cold War and American Science: the Military-Industrial-Academic Complex at MIT and Stanford* (New York: Columbia University Press, 1993).

[51] Dale N. Hatfield, "Architecture as Policy," in Bolin, ed., *Standards Edge: Dynamic Tension*, 137-144.

[52] For examples of such programs, see the Internetworking Research Lab at the University of Delaware (http://www.eecis.udel.edu/~millslab); the Interdisciplinary Telecommunications Program at the University of Colorado at Boulder (http://itp.colorado.edu); and the Department of Information Science and Telecommunications at the University of Pittsburgh (http://www.sis.pitt.edu/~dist).

[53] Kenneth Krechmer, "The Principles of Open Standards," http:// www.ses-standards.org/library/krechmer.pdf; cf. Chris DiBona, Sam Ockman, and Mark Stone, eds., *Open Sources: Voices from the Open Source Revolution* (Cambridge, MA: O'Reilly, 1999).

[54] Kai Jakobs, *Standardisation Processes in IT: Impact, Problems, and Benefits of User Participation* (Lengerich: Vieweg, 2000); John Morris, Jr. and Alan Davidson, "Internet Technical Standards Setting Bodies: The Public Policy Venues of the Twenty-First Century," in Bolin, ed., *Standards Edge: Dynamic Tension*, 125-136.

[55] L. Jean Camp, "Design for Trust," in Rino Falcone, ed., *Trust, Reputation and Security: Theories and Practice* (New York: Springer, 2003); Helen Nissenbaum, "How Computer Systems Embody Values," *Computer* (March 2001): 118-120; Batya Friedman, ed., *Human Values and the Design of Computer Technology* (New York: Cambridge University Press, 1997).

[56] On technological innovation as a driver of globalization throughout the twentieth century, see Alfred E. Eckes, Jr., and Thomas W. Zeiler, *Globalization and the American Century* (New York: Cambridge University Press, 2003), 1-3, 245.

[57] Jonathan E. Nuechterlein and Philip J. Weiser, *Digital Crossroads: American Telecommunications Policy in the Internet Age* (Cambridge, MA: The MIT Press, 2005), chapter 12.

This essay investigates both views, but I am personally inclined to the latter opinion. According to some people, learning history is a waste of time and energy. They believe that learning technology and science can bring significantly more benefits to the humankind and the knowledge could be utilised for future development. History, on the contrary, has no utilisation in our daily life, according to them.Â Finally, teaching history in school helps foster patriotism among the youth which is quite important for a bright future generation. In conclusion, people learn important lessons from experience and to build a prosperous nation, we must learn from our history which offers the greatest experience of all. Without knowledge of history, scientific discoveries alone cannot bring a wide range of advantages. Standardization or standardisation is the process of implementing and developing technical standards based on the consensus of different parties that include firms, users, interest groups, standards organizations and governments. Standardization can help maximize compatibility, interoperability, safety, repeatability, or quality. It can also facilitate commoditization of formerly custom processes. In social sciences, including economics, the idea of standardization is close to the solution for a Standardization in History: A Review Essay with an Eye to the Future, In: The Standards Edge: Future Generations, Bolin, S. (Ed.), pp. 247-260, Ann Arbor. [4] David, P. A. (1987). Some new standards for the economics of standardization in the information age. In: Economic Policy and Technological Performance. Dasgupta, P., Stoneman P. (Eds.) Cambrige University Press, London. [5] Farrell, J. & Saloner, G. (1985). Examples of Standardization in Trading. Standardization is commonplace in the financial markets, which helps facilitate trades and financial transactions involving all of the participants, such as investors, brokers, and fund managers. Stock Orders. In the stock market, the standard minimum stock order that can be placed through an exchange without incurring higher commission fees is 100 shares. These standardized lots are set by exchanges, such as the New York Stock Exchange (NYSE), to allow for consistency and greater liquidity in the markets. The increased liquidity means that investors can