

# Telecommunications Standards in the Second and Third Industrial Revolutions

**Telecommunications networks provide foundations for modern industrial societies. These networks are built around standards. Both the technical attributes of these standards, and the institutions used to create and maintain standards, changed radically over the course of the twentieth century. A close examination of these changes in standardisation illustrates points of continuity and change in the transition from the Second to the Third Industrial Revolution in the late twentieth century.**

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## Introduction

Consider the black telephone shown in Figure 1<sup>1</sup>, an icon of American telecommunications during the era of AT&T's regulated monopoly.

This is one of the 500 series telephones offered by the Bell System between 1949 and 1986. It was one of hundreds of commercial products based on technologies developed in Bell Labs and made by AT&T's manufacturing subsidiary Western Electric. Customers would have subscribed to local service from their regional Bell Operating Company and long distance service from AT&T Long Lines. This telephone is thus

**Figure 1** Western Electric 500 C/D rotary dial telephone, circa 1958



both a symbol and an artefact of the Bell System's complete dominance of the American telecommunications industry throughout the middle of the twentieth century<sup>†</sup>.

Consider now a second telephone shown in Figure 2<sup>3</sup>, a cellular telephone that is itself an icon of a more recent period in American telecommunications.

The telephone is wireless (there is no need to connect the telephone to the wall), cordless (the handset and the telephone are no longer two separate devices), and a fraction of the size of the Western Electric 500. Three markings on this telephone reveal the influence of a different group of institutions. The manufacturer (Kyocera) is a Japanese firm that was founded in 1959 as a ceramics company. The network operator (Verizon) is an American firm – financed in part by a British firm (Vodafone) – that is a composite of several fragments created by the breakup of the Bell System in 1984. The telephone can send both voice and data signals over wireless networks through a technology (3G CDMA) that was created by a California start-up firm (Qualcomm) in the late 1980s and standardised in an industry committee in the 1990s. The telephone can also be used to send text messages, play video games, and listen to music. The trademarks of the Bell System are absent – where we once would have seen markers showing their national monopoly, we now see evidence of an international alliance of private firms.

These two telephones illustrate fundamental changes in the organisations that created and operated telecommunications technology in the twentieth century. During the latter decades of the twentieth century, this institutional order changed

<sup>†</sup> This article is oriented around events in American history, but the overarching trends described may also be discerned in other nations, particularly in Western Europe. Readers might substitute examples from other nations – for example, by imagining the role of a particular European PTT where the text refers to the Bell System – and see the same historical trends at work. An excellent summary of changes in international standardisation can be found in Drake<sup>2</sup>.

**Figure 2** Kyocera KXI cellular telephone, circa 2005



from a regulated monopoly that used a hierarchical style of organisational control to an oligopoly in which authority was distributed between dozens of firms in Europe, North America, and East Asia. Fundamental transitions in telecommunications technology caused, and were caused by, changes in regulation and market structure. This article<sup>†</sup> explores these reflexive relationships between technology, politics, and business by focusing on the technical standards that provided the foundations for telecommunications networks.

### Three Industrial Revolutions

To appreciate the historical significance of the differences between the telephones shown in Figures 1 and 2, it is helpful to step back for a moment and consider the contours of change through three Industrial Revolutions in western capitalism<sup>4</sup>. Historians use the ‘industrial revolutions’ concept to describe fundamental transformations in systems of industrial production. This section discusses the characteristics of three Industrial Revolutions between the eighteenth and twentieth centuries in order to establish the broad context in which changes in telecommunications standards and standardisation played a major part.

The First Industrial Revolution occurred initially in England and later in France and the United States. Between the 1760s and 1840s, entrepreneurs harnessed water and steam power within the nascent factory system of production. Machine labour in factories began to replace tasks traditionally performed by manual labour. Through machines such as the flying shuttle and the steam engine, these factories manufactured items such as textiles, pottery, and metal goods, including firearms and grain reapers.

The chronological limits of the Second Industrial Revolution extend between the 1840s and the 1950s, with the most

significant changes occurring between the 1880s and 1920s in Germany, Britain, and the United States. The key technological developments during this period came through advances in chemicals and electricity, the widespread adoption of the internal combustion engine, and the rapid expansion of railways, telegraph, and telephone networks. By the early twentieth century, American regulators moved away from their traditional *laissez-faire* ideology in favour of an adversarial style of governance that used antitrust prosecution and industrial regulations to combat the excesses of industrial capitalism. This period in American history is known as an era of big business, dominated by massive corporations led by men such as John D Rockefeller, Andrew Carnegie, and J P Morgan. As the historian Alfred D Chandler, Jr has explained, corporate executives and managers drove this growth by creating large firms that co-ordinated more efficient methods of industrial production and distribution<sup>5</sup>.

The Third Industrial Revolution – the historical roots of popular concepts such as the ‘Information Age’ and the ‘Network Society’ – began in the 1950s in the United States, Japan, and Western Europe, and continues to the present day<sup>6–9</sup>. The technological foundations of the Third Industrial Revolution were innovations in computing and electronics, including the invention of transistors, integrated circuits, and digital computers and networks. Sea changes in American regulation occurred during this same period. Antitrust restrictions in the 1950s forced firms such as AT&T and RCA to license a number of key patents to competing firms, including a new group of entrepreneurial firms in a region of California that became known as the ‘Silicon Valley’. Most importantly, the American federal government assumed a greater role in fostering the nation’s scientific knowledge base through investments in the military and higher education.

By the late 1970s, American regulators initiated reforms that utilised privatisation and deregulation as strategies to increase productivity, stoke economic growth, and pave the way toward a more tightly integrated global economy. Executives in private firms responded to changes in technology and regulation by forging international partnerships with other firms through co-operative arrangements such as joint ventures and standards-setting institutions. Firms in sectors that were at one time distinct – telecommunications, computers, and consumer electronics – began to converge around a common set of

digital technologies. The next section shows how the transition from the Second to the Third Industrial Revolution is particularly evident when we examine changes in telecommunications technology.

### Standards in American Telecommunications

In the context of this discussion of successive Industrial Revolutions, telecommunications technology is especially revealing for two reasons:

- it provided foundations for commerce and social activity;
- it was an important site of technological innovation.

Standards were vital because they provided underlying stability for this dual role of telecommunications. Scholars use metaphors such as ‘information platforms’ and the ‘information infrastructure’ to characterise this stability<sup>10,11</sup>. Both metaphors draw our attention to the important role for standards for facilitating interoperability between technical components of communications networks. These networks, in turn, provided a basis for a diverse range of activities that are fundamental for industrial societies<sup>12</sup>.

The First Industrial Revolution is not the primary concern of this article, but it is important to recognise significant technological and ideological precedents for future telecommunications networks that were set in the late eighteenth and early nineteenth centuries. Historians who study this era of American history emphasise the crucial role of newspapers and the postal service in fostering wide access to news and information. For instance, Richard D Brown has suggested that Americans recognised the importance of the free flow of information in establishing a viable political culture ‘built on the Miltonic principle of open competition to establish truth in people’s minds’<sup>13</sup>. This principle, codified in the First Amendment of the American constitution in 1787, was evident in government subsidies for newspaper delivery through the Post Office Department.

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<sup>†</sup> This article is based on a paper that was presented at the ‘Cross connexions – history of communications’ conference which took place at the Science Museum, London, 11–13 November 2005.

The American information infrastructure grew as two foundational networks of the Second Industrial Revolution – the railway and the telegraph – matured in the second half of the nineteenth century. These networks were the site of important technical innovations as well as experiments in administrative control. By the 1860s, the symbiotic growth of railway and telegraph networks provided an essential infrastructure for American commerce and westward expansion. The growth of these networks was concentrated in a handful of powerful institutions, such as the Western Union telegraph monopoly and railway oligopolists such as the New York & Erie, Baltimore & Ohio, and Pennsylvania Railroads.

These public and private institutions experimented with a diverse range of administrative controls, including the establishment of regular postal routes, punctual telegraph messenger boys, and communication protocols such as Morse code. A striking example of the organisational capabilities generated by these experiments may be seen in the career of Theodore N Vail. In the 1870s, Vail served as the superintendent of Fast Mail, an experiment of the Post Office Department that used the railways for high-speed mail delivery trains that ran between New York and Chicago. In Richard John's assessment, Vail's experience with the administration of the complex Fast Mail communications network was influential when, later in his career, he became president of AT&T from 1885 to 1889 and again from 1907 to 1919, where he was the principal architect of the third foundational network of the Second Industrial Revolution – the Bell System<sup>14</sup>.

Starting in the early days of the Bell System, executives such as Gardiner Hubbard relied extensively on standards to create a nationwide telephone network. Standards helped to improve the efficiency and reliability of network equipment. Bell executives also used standards as a rationale for refusing to interconnect with competing telephone companies that used inferior criteria, on the grounds that these lesser systems would introduce interference into AT&T's entire network. In the early twentieth century, Bell System executives Theodore Vail and E J Hall were especially active in continuing to use technical standards as barriers to entry. Their tactics introduced a new element of protection for their network: they persuaded state regulators to require high technical standards that many of Bell's competitors found too costly to meet<sup>15-17</sup>.

The Bell System also relied on standardisation to create efficiencies in

manufacturing and production.<sup>18, 19</sup> During Theodore Vail's second tenure as AT&T president (1907–1919), the Bell System developed an innovation strategy that relied on company-wide standardisation to introduce new technologies throughout the entire Bell System<sup>20</sup>. This style of innovation has been characterised by historian Thomas Hughes as 'systems innovation', in which a single individual or firm oversaw the creation of individual components as well as a system architecture in which all the components worked together. Thomas Edison, Samuel Insull, and Vail are just a few of the many individuals who created successful enterprises based on systems innovations in the Second Industrial Revolution<sup>21</sup>.

This tradition of systems innovation in the Bell System continued beyond Vail's tenure at the head of AT&T, as was evident in a 1931 presentation by AT&T engineer H S Osborne. Osborne's examples included:

- the standardisation of telephone plant design;
- raw materials;
- manufacturing plants;
- equipment and processes;
- distribution and installation;
- business and accounting methods;
- provisions for safety and health.

These standardisation efforts, Osborne noted, were 'more than a means of obtaining economy and efficiency ...', they were '...the result of the accumulated experience of the operating companies and the work of several thousand people at headquarters whose time is devoted to improvements'<sup>22</sup>. Standards within the Bell System, then, provided a record of the technical know-how and organisational capabilities of individuals who worked for the Bell System.

Plainly, standards were the glue that held the Bell System together. They were as essential for the initial growth of its telephone network in the nineteenth century as they were for its continued survival as a hierarchically integrated institution in the twentieth century.

In many cases, however, Bell managers and engineers also had to co-operate with

external organisations to develop standards. These sorts of co-operative relationships in the 1920s and 1930s generated essential standards for international telephone connectivity, fire safety, electrical lighting and power supply, and raw materials such as brass, silver, bronze, and wood. The participation of dozens of Bell managers and engineers in a number of industry standards committees shows that even this powerful monopoly benefited from the consensual exchange of technical information in standards committees, such as the American Standards Association, the American Institute of Electrical Engineers, the American Railway Association, the Institute of Radio Engineers, the American Society for Testing Materials, the National Electric Light Association, and the International Electrotechnical Commission.

These co-operative links between competing firms in standards committees moved to centre stage as the telecommunications industry experienced drastic changes during the last third of the twentieth century. New technologies – some created within the Bell System, some from outside organisations – forced changes to the Bell System's established order for setting standards. The period between the 1960s and 1990s is aptly characterised as a period of 'technological convergence,' defined by one recent textbook as 'the coming together of different technologies to provide similar services'<sup>23</sup>. This era of convergence has been marked by the adoption of digital technologies in the transmission of telephone, television, and radio signals. By the 1980s and 1990s, the American telephone system expanded to carry digital voice and data traffic and attach to different types of telephones, including wireless telephones. These new, more robust, digital technologies blurred the distinctions between entire industries that were once separate – today, customers can listen to the radio on their computers, use their telephones to watch movies, and use their cable television connections for voice communications.

In the decades that the new digital networks were under development, the Bell System was fighting in vain to protect its monopoly from waves of attacks from

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regulators and market competitors. The next section examines these attacks on the Bell System in the pivotal years between the mid-1950s and the 1980s, and explores some characteristics of the new institutions that assumed the co-ordinating functions that were once performed inside the Bell System.

## Transitions in Standardisation – Politics and Business Between the Second and Third Industrial Revolutions

How did changes in politics and business lead to the rise of new institutions to co-ordinate digital telecommunications standards? From the mid-1950s through the 1980s, a series of unco-ordinated acts of policy entrepreneurship destroyed the Bell System's chokehold on innovation in American telecommunications. This section describes the regulatory changes that dismantled the Bell System's hierarchical control of standardisation and the subsequent changes in telecommunications market structure and business strategies that rendered the Bell style of standardisation obsolete<sup>24, 25</sup>.

A series of actions by the Department of Justice and the Federal Communications Commission (FCC) had a direct influence on control over existing standards and the process for setting standards for the connection of equipment to the network. A 1956 Consent Decree between AT&T and the Department of Justice prevented both AT&T and its Western Electric manufacturing subsidiary from entering markets outside the common carrier telephone service, thus restricting the Bell System's ability to control the interfaces and standards for future generations of information processing and computer networks. Additionally, by forcing the Bell System to license its patents at reasonable rates, the Consent Decree forever ended an era in which Bell System executives such as Hall and Vail used patents as strategic tools to marginalise competitors.

Subsequent interventions by the FCC exerted a direct influence on specific standards as well as the standards-setting process. A major thrust of these interventions was to facilitate competition in markets for customer premises equipment, including devices such as telephones, network switches, and computer modems that users could attach to the network. A series of hearings and decisions between 1968 and the late 1980s

(including the Carterfone decision, the FCC's Part 68 rules, and the FCC's Computer Inquiries) extended the FCC's control over interconnection standards for the telephone network and, significantly, restricted AT&T's ability to compete in the nascent computer networking and data processing<sup>23</sup>. The final, decisive blow to the Bell System's influence in the standards process came with the January 1982 agreement between AT&T and the Justice Department to break up the Bell monopoly and create a new market structure for the telecommunications industry.

The FCC, faced with the oversight of this frenzied period in telecommunications history, was distinctly uncomfortable in its new role<sup>†</sup>. Instead of taking a leading role in setting rules and standards for the new digital networks, the FCC adopted the logic and language of deregulation. One FCC advisor summarised the changing ideology at the FCC: 'There is a tendency of regulators to automatically impose legacy regulation on new services that appear similar to, substitutes of [sic], or threats to traditional services. The policymaker must always ask why. Why impose legacy regulation on the new service?'<sup>27</sup>

Between 1983 and 1988, the FCC hesitated to exercise direct authority over standards-setting, preferring instead to rely on industry committees to co-ordinate the technical choices of private firms. In 1983, the FCC approved the creation of an industry committee named T1 to maintain interconnection standards for the telephone network, thus filling the void left by AT&T's divestiture. The T1 committee was founded in 1984 on the principles of 'pluralistic corporate participation, due process, transparency, and weighted voting where necessary.'<sup>2, 28</sup> These principles for 'voluntary consensus' standards, which had been developed and shepherded in a number of industries since the early twentieth century through the American National Standards Institute, provided a ready alternative for the new industry structure of American telecommunications. In 1988, the FCC decided to defer to industry committees to set standards for digital cellular networks, thus cementing its commitment to avoid mandating standards in the post-monopoly era<sup>29</sup>.

During the transition from a monopolistic to a competitive industry structure in telecommunications, the same forces behind this change – antitrust prosecution and a flood of competition based on new technologies – altered the structure of the computing industry as well. For several decades after the Second World War, IBM was successful in using a systems

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innovation strategy with Third Industrial Revolution computing technologies. By the early 1980s, however, this systems innovation strategy proved to be vulnerable to 'pure-play' strategies in which competitors such as Intel, Compaq, and Microsoft were rapidly gaining market share by specialising in narrow segments such as microchips, desktop computers, and software<sup>30</sup>.

Apart from the political factors discussed above, the increasing technical complexity of component design and manufacturing proved to be a leading cause of this disintermediation of the computer industry. Andrew Grove, the former CEO and President of Intel, summarised the new conventional wisdom: 'Simply put, it's harder to be the best of class in several fields than in just one.'<sup>31</sup> Strategic partnerships based around standardised interfaces generated market success, as evidenced by the cellular telephone in Figure 2, and by the dominance of the so-called 'Wintel' combination of the Microsoft Windows operating system on computers equipped with Intel processors.

The history of the Internet provides the clearest examples of the co-evolution of technologies and institutions in the Third Industrial Revolution. Starting in the late 1960s, researchers sponsored by the Department of Defense created packet-switched computer networks. By the late 1970s, these researchers had created a simple set of protocols (TCP/IP) to allow dissimilar networks to interconnect. The design of TCP/IP and related standards was led at first by programme managers at the Pentagon (including Robert Taylor, Vinton Cerf, and Robert Kahn), and later by a small group of engineers (including Jon Postel and David Clark) who built new standards-setting institutions from scratch. Through

<sup>†</sup> In one scholar's interpretation, the FCC retreated from an active regulatory role in the late 1970s and early 1980s because it was overwhelmed by the effects of years of lobbying pressure from a wide variety of interest groups – including consumer advocates, the telecommunication industry, Congress, the federal judiciary, the Department of Justice, and the White House<sup>26</sup>.

their commitment to transparent processes and broad participation, these institutions – especially the Internet Advisory Board and the Internet Engineering Task Force (IETF) – provided opportunities for a diverse mix of academic, government, and corporate engineers to exchange information and create new standards to make the Internet stronger and more useful.

Throughout the early history of the Internet, experiments with network design and institutional design occurred simultaneously. The most concise summary of the underlying values of the Internet standards process is the IETF's unofficial motto, 'We reject: kings, presidents, and voting. We believe in: rough consensus and running code.' This phrase – spoken by the leading Internet architect David Clark in 1992 – encapsulated the IETF's rejection of hierarchical decision making (through kings or presidents) and preference instead for iterative networking experiments that garnered a widespread consensus<sup>32–34</sup>.

The Internet standards community's commitment to 'running code' represents a jab at a competing set of standards for internetworking created by the International Organisation for Standardisation (ISO). In the eyes of Internet advocates, the ISO process lacked experimental value and flexibility while at the same time suffering from excessive bureaucratic constraints. David Mills, an influential Internet engineer in the 1980s and early 1990s, recalled the virtues of the Internet standards process: 'Internet standards tended to be those written for implementors. International (ISO) standards were written to be obeyed.'<sup>35</sup>

The Internet/ISO standards war was one of many examples of competition between standards bodies during the dynamic institutional environment in telecommunications and computing in the 1980s and 1990s. During this period, dozens of standards committees, industry consortia, and *ad hoc* alliances strove to exercise authority over standards for new digital networks. Committees, like individual firms, adopted 'pure-play' strategies in order to focus closely on complex and narrowly defined engineering problems. In the midst of these institutional turf battles, these committees also established liaisons to collaborate with one another in order to ensure that their products would be accepted by firms in other niches of the networking industry<sup>36</sup>. Many collective action problems lurked for standards committees in this dynamic and competitive environment; indeed, even though the IETF enjoyed engineering success in the 1980s and 1990s, it has struggled to maintain its

flexibility and agility, and continues to display several other problems characteristic of maturing organisations<sup>37, 38</sup>.

## Conclusions

As pundits in recent years have celebrated and hyped the new technologies of the 'digital revolution', they have mostly ignored the institutional changes that have been equally radical and equally important. A vivid reminder of the magnitude of this institutional regime change came with the 2005 sale of AT&T – ironically to SBC, one of its 'Baby Bell' offspring born in the 1984 divestiture. For the American telecommunications industry, the transition from national 'hierarchical entrepreneurship' in the Second Industrial Revolution to global 'alliance entrepreneurship' in the Third Industrial Revolution was complete<sup>39</sup>.

The two telephones pictured in the introduction are not simply telephones: they are artefacts produced by far-reaching technological and institutional changes in American telecommunications. They are symbols of the sweeping transition from stable hierarchical control over wired analogue networks to dynamic and decentralised control over digital and wireless networks. These changes present significant historical questions.

- What is new about telecommunications standardisation in the Third Industrial Revolution?
- Where are the continuities from earlier Industrial Revolutions?
- Where are the fundamental shifts?

In the realm of technology, digital and wireless networks and devices are new, but the growth of these networks – especially the Internet – relied heavily on the legacy wired infrastructure of the Bell System to facilitate voice, text, and video communications. In the realm of politics, antitrust enforcement has undergone a radical shift from aggressive enforcement between the 1950s and the 1980s to a 'bold experiment' begun under President Ronald Reagan to trust markets more than antitrust regulators<sup>40</sup>. Federal regulators have all but abandoned the price and entry regulations that for decades formed the centrepieces of their relationship with the Bell monopoly. Instead, the most significant regulatory questions facing Internet standards stem from foundering attempts to place the Internet under the control of the United Nations<sup>41</sup>. In the realm of business, research and development for American telecommunications networks no longer occurs exclusively within Bell Labs. Instead,

hundreds of firms around the globe collaborate and compete within standards committees that, in turn, collaborate and compete with one another<sup>42, 43</sup>.

Regulators in the United States and Western Europe have responded to Third Industrial Revolution technologies by forging different styles of alliances. This article has discussed how American regulators rejected a hierarchical control through monopoly or unilateral regulation in favour of a pluralistic and decentralised industry-driven approach that generates and maintains standards through market and committee competition<sup>44</sup>. European regulators, motivated by the logic of regional harmonisation, opted for a more active regulatory role in directing the standards process. In the 1980s and 1990s, authority in the European standards process shifted from national regulators and monopoly firms to regional bodies such as the European Telecommunications Standards Institute (ETSI) in which private manufacturers play a dominant role. Despite significant differences in geography and political economy, Americans and Europeans have forged remarkably similar responses to the technical and organisational challenges of the Third Industrial Revolution. In both places, standardisation institutions new and old have been of utmost importance for this transfer of power from national governments and monopolies to international alliances of private firms.

The telecommunications industry has displayed a new reliance on inter-firm standards committees, but it would be a mistake to conclude that these committees represent a new model of industrial organisation. Engineers in the telecommunications industry did not invent the industry-wide committee approach to setting standards. Since the late nineteenth

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century, thousands of technical standards have been published by industry committees in sectors that have not been dominated by one or two firms<sup>45-47</sup>. Even the monopolistic Bell System needed to participate in over a dozen industry standards committees to co-ordinate activities that could not be controlled within the Bell System hierarchy. When technology and regulation changed the industry structures of telecommunications and computing in the 1970s, 80s, and 90s, engineers and regulators relied on the pluralistic principles of industry standards committees in order to co-ordinate their responses to the Third Industrial Revolution.

## References

- 1 Bell System Memorial – [http://www.bellsystemmemorial.com/images/we\\_500cd.jpg](http://www.bellsystemmemorial.com/images/we_500cd.jpg)
- 2 Drake, W. The Transformation of International Telecommunications Standardization: European and Global Dimensions. In Steinfield, C., Bauer, J., and Caby, L. (Eds). *Telecommunications in Transition: Policies, Services, and Technologies in the European Community*. Thousand Oaks, California, Sage Publications, 1994.
- 3 Artefact in possession of author. Photograph by Tara Greaver.
- 4 McCraw, T. (Ed). *Creating Modern Capitalism: How Entrepreneurs, Companies, and Countries Triumphed in Three Industrial Revolutions*. Cambridge, Massachusetts, Harvard University Press, 1995 (pp 12-16 in particular).
- 5 Chandler, A. *The Visible Hand: The Managerial Revolution in American Business*. Cambridge, Massachusetts, Belknap Press, 1977.
- 6 Galambos, L. Recasting the Organizational Synthesis: Structure and Process in the Twentieth and Twenty-First Centuries. *Business History Review*, Spring 2005, **79**, pp 5-19 in particular.
- 7 Chandler, A. and Cortada, J. (Eds). *A Nation Transformed by Information: How Information Has Shaped the United States from Colonial Times to the Present*. New York, Oxford University Press, 2000.
- 8 Castells, M. *The Rise of the Network Society*. Oxford, Blackwell Publishers, 1996.
- 9 Beniger, J. *The Control Revolution: Technological and Economic Origins of the Information Society*. Cambridge, Massachusetts, Harvard University Press, 1986.
- 10 Weiser, P. Law and Information Platforms. *Journal of Telecommunications and High Technology Law*, 2002, **1**(1).
- 11 Kahin, B. and Branscomb, L. (Eds). *Standards Policy for Information Infrastructure*. Cambridge, Massachusetts, The MIT Press, 1995.
- 12 David, P. and Steinmueller, W. Economics of Compatibility Standards and Competition in Telecommunication Networks. *Information Economics and Policy*, 1994, **6**.
- 13 Brown, R. Early American Origins of the Information Age. In Chandler, A. and Cortada, J. (Eds). *A Nation Transformed by Information: How Information Has Shaped the United States from Colonial Times to the Present*. New York, Oxford University Press, 2000, p 52.
- 14 John, R. Recasting the Information Infrastructure for the Information Age. In Chandler, A. and Cortada, J. (Eds). *A Nation Transformed by Information: How Information Has Shaped the United States from Colonial Times to the Present*. New York, Oxford University Press, 2000, pp 72, 99-100.
- 15 Mueller, M. *Universal Service: Competition, Interconnection, and Monopoly in the Making of the American Telephone System*. Cambridge, Massachusetts, The MIT Press, 1997.
- 16 Garnet, R. *The Telephone Enterprise: The Evolution of the Bell System's Horizontal Structure, 1876-1909*. Baltimore, The Johns Hopkins University Press, 1985.
- 17 John, R. Recasting the Information Infrastructure for the Information Age. In Chandler, A. and Cortada, J. (Eds). *A Nation Transformed by Information: How Information Has Shaped the United States from Colonial Times to the Present*. New York, Oxford University Press, 2000, pp 90 and 95-6.
- 18 Gillespie, R. *Manufacturing Knowledge: A History of the Hawthorne Experiments*. New York, Cambridge University Press, 1991.
- 19 Noble, D. *America By Design: Science, Technology, and the Rise of Corporate Capitalism*. New York, Knopf, 1977.
- 20 Galambos, L. Theodore N Vail and the Role of Innovation in the Modern Bell System. *Business History Review*, 1992, **66**.
- 21 Hughes, T. *Networks of Power: Electrification in Western Society, 1880-1930*. Baltimore, The Johns Hopkins University Press, 1983.
- 22 Osborne, H. The Fundamental Role of Standardization in the Operations of the Bell System. *American Standards Association Bulletin*, Sept 1931, pp 3, 15.
- 23 Nuechterlein, J. and Weiser, P. *Digital Crossroads: American Telecommunications Policy in the Digital Age*. Cambridge, Massachusetts, The MIT Press, 2005, pp 24, 57-59, 149-155.
- 24 Vietor, R. *Contrived Competition: Regulation and Deregulation in America*. Cambridge, Massachusetts, Harvard University Press, 1994.
- 25 Temin, P. and Galambos, L. *The Fall of the Bell System: A Study in Prices and Politics*. New York, Cambridge University Press, 1987.
- 26 Heffron, F. *The Federal Communications Commission and Broadcast Deregulation*. In Havick, J. (Ed). *Communications Policy and the Political Process*. Westport, Connecticut, Greenwood Press, 1983.
- 27 Cannon, R. The Legacy of the Federal Communication Commission's Computer Inquiries. *Federal Communications Law Journal*, 2003, **55**, p 205.
- 28 Lifchus, I. Standard Committee T1-Telecommunications. *IEEE Communications Magazine*, Jan 1985.
- 29 Federal Communications Commission. Report and Order, Gen Docket 87-390, p 25 FCC Rcd 3d 7033, 1988.
- 30 Galambos, L. Recasting the Organizational Synthesis: Structure and Process in the Twentieth and Twenty-First Centuries. *Business History Review*, Spring 2005, **79**, pp 16-19.
- 31 Grove, A. *Only the Paranoid Survive: How to Exploit the Crisis Points That Challenge Every Company and Career*. New York, Doubleday, 1996, p 52.
- 32 Russell, A. Rough Consensus and Running Code and the Internet-OSI Standards War. *IEEE Annals of the History of Computing*, in press.
- 33 Froomkin, A. Habermas@Discourse.Net: Toward a Critical Theory of Cyberspace. *Harvard Law Review*, 2003, **116**(3).
- 34 Drake, W. The Internet Religious War. *Telecommunications Policy*, Dec 1993.
- 35 Mills, D. Interview in Newark, Delaware, February 26, 2004.
- 36 IETF liaison – <http://www.ietf.org/liaisonActivities.html>
- 37 Alvestrand, H. (Ed). IETF Mission Statement. RFC3935, 2004 – <http://www.ietf.org/rfc/rfc3935.txt>
- 38 Austein, R. and Wijnen, B. (Eds). Structure of the IETF Administrative Support Activity (IASA). RFC4071, 2005 – <http://www.ietf.org/rfc/rfc4071.txt>
- 39 Galambos, L. and Abrahamson, E. *Anytime, Anywhere: Entrepreneurship and the Creation of a Wireless World*. New York, Cambridge University Press, 2002, p 255.
- 40 Galambos, L. The Monopoly Enigma, the Reagan Administration's Antitrust Experiment, and the Global Economy. In Lipartito, K. and Sicilia, D. (Eds). *Constructing Corporate America: History, Politics, Culture*. New York, Oxford University Press, 2004.
- 41 Cukier, K. Who Will Control the Internet? *Foreign Affairs*, Nov/Dec 2005.

- 42 Funk, J. *Global Competition Between and Within Standards*. London, Palgrave, 2002.
- 43 Deutsch, D. Coordinating Oracle Participation in External Standards-Setting Organizations. In Bolin, S. (Ed). *The Standards Edge: Dynamic Tension*. Ann Arbor, Michigan, Sheridan Books, 2004.
- 44 Marks, R. and Hebner, R. Government/Industry Interactions in the Global Standards System. In Bolin, S. (Ed). *The Standards Edge: Dynamic Tension*. Ann Arbor, Michigan, Sheridan Books, 2004.
- 45 Toth, R. *Standards Activities of Organizations in the United States*. Gaithersburg, Maryland, National Institute of Standards and Technology, 1996.
- 46 Sinclair, B. At the Turn of a Screw: William Sellers, the Franklin Institute, and a Standard American Thread. *Technology and Culture*, 1969, 10.
- 47 Thompson, G. Intercompany Technical Standardization in the Early American Automobile Industry. *Journal of Economic History*, 1954, 14(1).

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