CHAPTER ONE

What are Digital Infrastructures?

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Introduction

In a world that continues to increase in size and complexity, the dependence on information technologies (IT) that drive our life support systems is growing rapidly. Few other technologies have spread as rapidly. This book addresses the pervasive influence that IT has had on infrastructure, namely transportation, water supply and wastewater management, energy, and telecommunications, and its users. This is especially timely in light of the growing need for critical policy, management and technological choices about the reliability and security of IT and infrastructure systems, and in particular what was deemed critical infrastructure by the President's Commission on Critical Infrastructure Protection in 1997 (US Department of Commerce, Critical Infrastructure Assurance Office 1997) and again in 2003 by the White House (White House 2003).

As a point of departure, it is clear that digital technologies have enabled our core infrastructures to expand geographically and in terms of functional capability; for example, our transportation systems are now managed through regional information systems that can monitor conditions on different roadway systems and across transportation modes. Indeed, our cities and towns are now fundamentally dependent on technology to provide a range of monitoring, diagnostic, and control information that allows our society to function smoothly with little or no interruption and under a wide range of conditions. Users increasingly have enhanced options to interact with infrastructure, as a result of the expanded infrastructure capabilities IT can provide.

But as Edward Tenner (1996) bluntly put it: "things bite back." For infrastructure managers, the implication is this: when IT is incorporated into the design of infrastructure systems for high performance, it can beget new problems with infrastructures and create unintended consequences.

The technology sword indeed has two edges: one edge facilitates unprecedented infrastructure performance and the other edge allows for dramatic infrastructure failure when environmental and/or technological conditions run afoul. This second edge of the sword was felt in 2003 when history repeated itself with a number of electric power blackouts around the world of magnitudes rarely seen before – in the United States, Canada, the United Kingdom, Italy, Sweden and Denmark. In a number of those cases, cyber failures were not or have not yet been identified as initiators. But the blackout of August 14, 2003, that affected about 50 million people across the northeastern and mid-western US and Canada making it the largest blackout, did have cyber origins in the form of software and computer failures according to the US-Canada Power System Outage Task Force (2004: 51–55).

The story does not stop there. A growing literature on the interdependencies among different kinds of infrastructure (see for example O'Rourke 1993; Rinaldi *et al.* 2001) underscores the fact that what starts out as an IT failure can quickly propagate throughout other systems. The causes can be accidents, natural hazards, or acts of terrorism, and IT failures range from very localized breaches of transmission lines, such as fiber optic cable, to more extensive main computer server outages. A common example of a localized breach is damage to fiber optic cable by construction crews, called "backhoe fading," which has been considered the largest source of public telephone network failures (Schneider 1999: 37). One such incident where an electrical power failure caused a breakdown of a phone system ultimately resulted in a shutdown at one of the three New York region airports in Newark, NJ (Hevesi 1991: A1). An example of a more extensive, and potentially very damaging IT failure is a breakdown of portions of the UUNet (Unix to Unix Network) backbone (UUNET Technologies, Inc., Fairfax, VA) that is central to the functioning of the Internet. One such failure occurred when nine out of 13 Domain Name System (DNS) root servers "responsible for helping to resolve domain names to their respective IPs" failed for an hour on October 22, 2002; another occurred in 1997 when seven of the servers were disabled (Internet Traffic Report 2002).[1] IT failures such as these can have a demonstrable impact on the real-time operation and long-term viability of civil and environmental infrastructures as they become increasingly dependent upon IT.

In addition to accidental disruptions, such as blackouts, acts of terrorism that target cyber infrastructure or indirectly damage it, have yielded even more pronounced impacts on infrastructure because of its interdependencies with IT. The September 11, 2001 attacks underscored the fact that while infrastructure may not be the direct target, indirectly the damages to IT facilities housed in destroyed buildings, and destruction or overloading of communication systems had widespread effects, for example, on vital communication capabilities to allow transportation and financial institutions to function (Zimmerman 2003) and on domain name servers as far away as South Africa (National Research Council 2002b).

The interdependencies are economic and social as well as physical. IT potentially primes the economic engine of infrastructure, which in turn affects the rest of the economy. The social implications of the growing dependency of society in general on IT, the "digital divide," have commonly been portrayed in terms of access to computers (US Department of Commerce 2000), and some have carried this further, pointing out that the cultural and social contexts of computer usage and educational support are equally important (Warschauer 2003). Consumers of infrastructure services are increasingly faced with IT-embedded service usage and payment systems where knowledge and proficiency with these systems is required to access infrastructure services.

Thus, the enabling of infrastructure by IT encompasses a very wide range of issues that need to be confronted to reinforce the positive features of IT and overcome the negative ones. It is for this reason that IT is identified as an important area for attention in terms of protecting and enhancing "critical infrastructures" in the US as well as internationally (Wenger *et al.* 2002).

Origins of this volume

This book had its origins in a workshop funded by the National Science Foundation (NSF) in June 2001, entitled, "Bringing Information Technology to Infrastructure: A Workshop to Develop a Research Agenda."[2] The purpose of the workshop was to identify research ideas for information technology and infrastructure around the themes of technology, management, and policy (Zimmerman *et al.* 2002). The workshop white papers and discussions revealed significant issues in each of these areas, as well as a host of crosscutting themes. In technology, new approaches to infrastructure system sensing, monitoring and control were outlined, including the use of new models to support the diagnosis of infrastructure systems for condition and vulnerability assessments. From the management discussions, it became clear that IT was shaping infrastructure organizations and organizational processes and had the potential to break down jurisdictional barriers among different kinds of infrastructure systems. In terms of policy, a host of federal, state and local policy directions were viewed as seriously affecting the nature, timing and use of IT in infrastructure systems. Some of the research needs identified at the workshop were issues regarding differential access by different populations and users of infrastructure to IT, security and privacy concerns, and the need for computer and analytical tools to support policy development.

While the workshop identified critical areas for attention, participants noted the paucity of integrated treatments of the IT and infrastructure intersection. This volume is aimed at providing such an integrated treatment by including both cross-infrastructure analyses of IT issues as well as indepth case analyses of IT uses in specific industries, recognizing that specific cases often have very widespread implications in spite of very specific, localized origins. Moreover, this volume strives to balance technical dimensions with social, organizational, and policy considerations. This integration can be seen in the conceptual framework that provides a foundation for the chapters.

A Conceptual Framework

This volume has a consistent underlying orientation regarding the role of digital technologies in civil and environmental infrastructures. The Management chapter (Chapter 3) explicitly addresses this orientation in the form of a "Conceptual Model for Managing Digital Infrastructures" (see Figure 3.1). While Chapter 3 describes the model in detail, it is worth introducing its components here as it represents a useful schema for considering the broader domain of digital infrastructures. The key consideration is that digital infrastructure systems are viewed as having several interweaving socio-technical dimensions. The first such dimension is the physical infrastructure itself (e.g. water, transport, electricity, telecommunications). Upon this platform rests the IT dimension that contains electronic means by which the infrastructure can be sensed, monitored, analyzed, and controlled. Surrounding the IT and physical layers are various users and institutional and policy actors. Users interact with the infrastructure, based on their demands for services and information they may need about the infrastructure services (e.g. price, quality, availability). In addition to end-users are a variety of public and private institutions that plan, manage, regulate, operate, and otherwise service the infrastructure and its digital features. Finally, these institutions are enmeshed in social, economic, policy and physical contexts that set various boundary conditions on the infrastructure, its users, and managing organizations. In many ways, this volume is a journey into how these various components interact with each other across infrastructures and under varying conditions of deployment and performance.

Information Technology and Infrastructure Overview

Definitions

This volume uses the term information technologies (IT) broadly to encompass information, communications and computing functions. Another term, information and communication technology (ICT) is also commonly used to portray information technology and the communication component, and the sectors that comprise these activities as defined by the OECD in 1998 and revisited in 2002.[3] The chapters in this book generally use IT as the term of choice though it can be considered to encompass ICT. Certain communications functions are often collectively referred to as telecommunications.[4] Computing infrastructure has been subdivided further into the following components: "the Internet, embedded/real-time computing (e.g. avionics systems for aircraft control, Supervisory Control and Data Acquisition (SCADA) systems controlling electrical energy distribution), and dedicated computing devices (e.g. desktop computers)" (NRC 2002b: 135). Finally, digital technologies is another term used to characterize portions of the information technology sector. Chapter 2 addresses the full range of sensing, monitoring, control and communications functionalities that many of these systems encompass. Chapter 9 gives the economic sectors in the US economy that typically comprise information technologies.

The Expanse of Infrastructure and its Growth Trends

Both traditional infrastructure and IT have grown dramatically over the past century and are expected to continue to be robust in the twenty-first century. They often share the same customers or markets as well as the underlying machinery providing the services and the sites where these services are provided.

Major infrastructure systems continue to link cities and regions throughout the world with massive distribution systems that now require IT for access to information and services from remote locations. In the US for example there are about four million miles of federal and state roadways, about 100,000 miles of rail lines for the largest of the systems (US Department of Commerce, Critical Infrastructure Assurance Office 1997: A-11), about one million miles of major water lines, hundreds of thousands of miles of oil and gas lines (NRC 2002a) and in excess of 200,000 miles of electric power transmission lines that provide 230,000 volts or more (US-Canada Power System Outage Task Force 2003: 3). These are a testament to the ability of infrastructure to transgress large spaces, yet can IT keep up?

Trends in infrastructure usage, many of which are described in other chapters, underscore its dramatic growth over the past few decades, and the task at hand for IT. Changes that occurred within the US exemplify the steady if not explosive use of infrastructure:

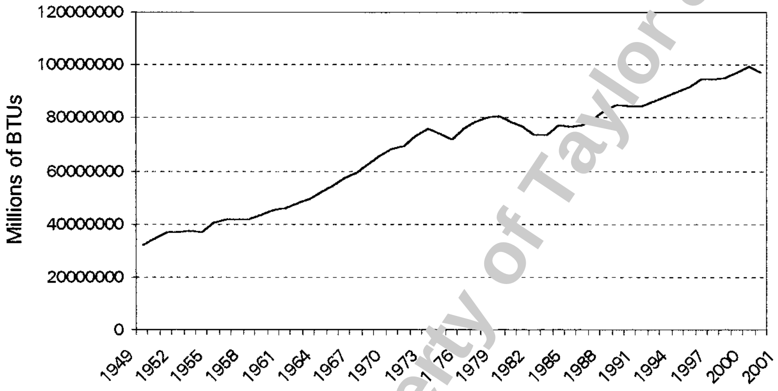
- By 2001, total energy consumption was three times what it was in 1949 (Figure 1.1); electricity use grew by a factor of thirteen over that same period (US Department of Energy, Energy Information Administration (EIA) 2001) as shown in Figure 1.2. When growth rates for population and the gross domestic product (GDP) are taken into account, the trend is less dramatic but still sizable. Using US Department of Commerce figures, between 1949 and 2001, population grew by 91 percent (from 149 million to 285 million) (US Department of Commerce, Bureau of the Census 2003: Table B-34, 317) and real GDP by 600 percent, which translates into a growth of 57 percent in per capita energy consumption and a decline from 20.6 thousand BTUs per dollar of real GDP to 10.6 thousand by 2002 (US Department of Commerce undated web site: Table 1.1.6).

- Most measures of automobile travel show a steady rise over the twentieth century. Growth in vehicle miles of travel, for example, approximates a linear trend over the decade of the 1990s (see Figure 1.3 and Chapter 6).

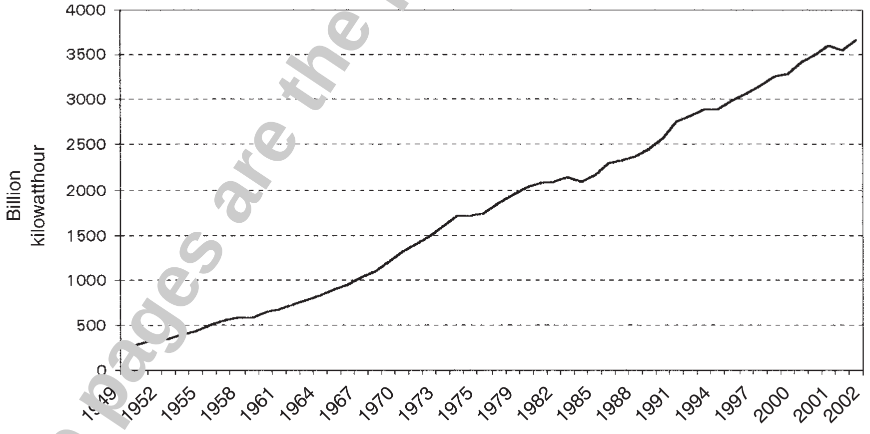
- Public transit usage as shown in Figure 1.4 increased by 8.2 percent from 1998 to 2002 (based on data from the American Public Transportation Association (APTA) 2002). Chapter 6 in this volume points out that the highest level of public transit travel occurred in 1946. Ridership declined through the 1970s, then increased, and stabilized in the early part of the twenty-first century.

- Water usage between 1950 and 1995 rose by 123 percent (see Figure 1.5), and population rose during that period by 72.6 percent (US Bureau of the Census 2000). The details of this trend are provided in Chapter 5.

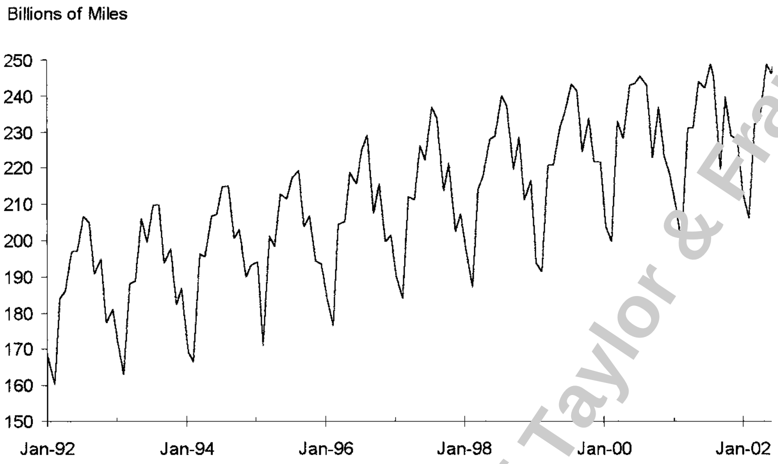
One important factor in being able to keep up with this demand is the service and design life of facilities. Though estimates are highly variable depending on facility usage, materials, and condition standards, design lifetimes for



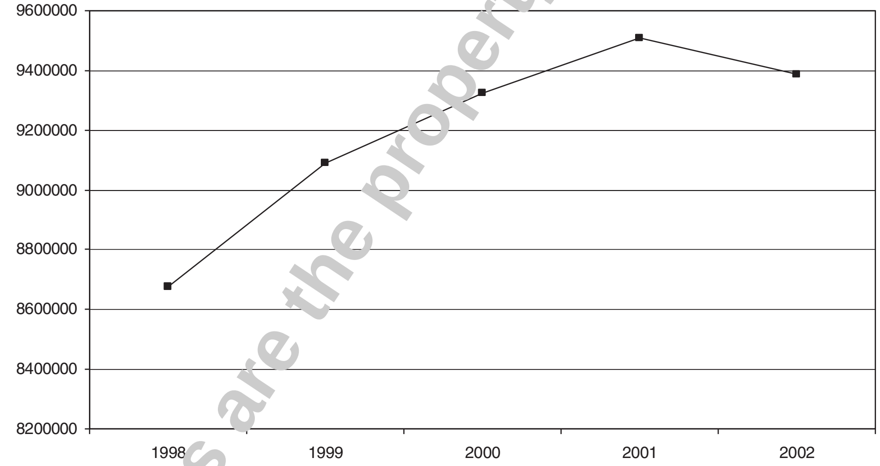
1.1 *Total Energy Consumption, United States, 1949–2001.*
Source: Graphed from data provided in Energy Information Administration (EIA) US Department of Energy (2001) *Annual Energy Review 2001*, Energy Perspectives: Trends and Milestones 1949–2001, Table 1.3, Online. Available at: http://www.eia.doe.gov/emeu/aer/txt/ptb0103.html.



1.2 *Electricity Use, United States, 1949–2002.*
Source: Graphed from data provided in Energy Information Administration (EIA) US Department of Energy (2001) *Annual Energy Review 2001*, Energy Perspectives: Trends and Milestones 1949–2001, Table 8.1, Online. Available at: http://www.eia.doe.gov/emeu/aer/txt/ptb0801.html.

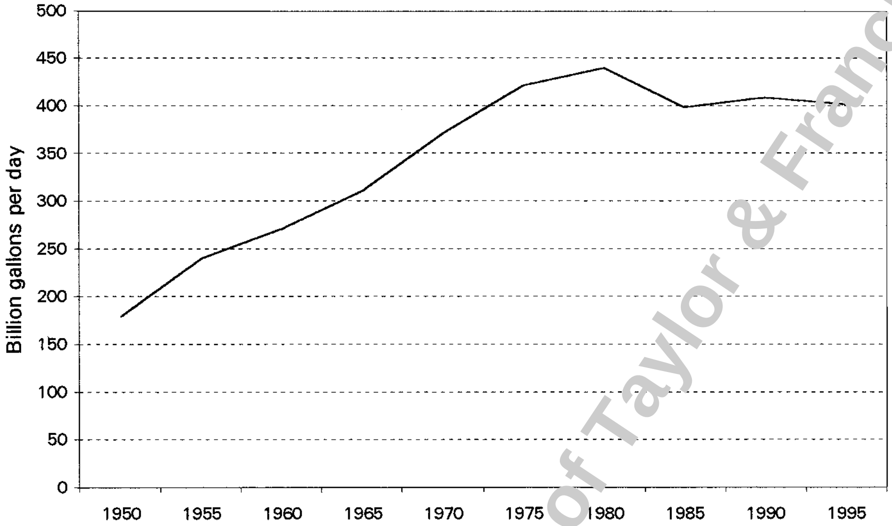


1.3 *Vehicle Miles of Travel, United States, 1992–2002.*
Source: US Department of Transportation, Federal Highway Administration, Office of Highway Policy Information, Online. Available at: http://www.fhwa.dot. gov/ohim/tvtw/tvtpage.htm. Courtesy of the US Department of Transportation.



1.4 *Transit Trips, United States, 1998–2002.*
Source: Graphed using annual totals from monthly data from the American Public Transportation Association, "APTA Ridership Reports Statistics–United States Mode Totals; APTA Quarterly Transit Ridership Reports", Online. Available at: http://www.apta.com/research/stats/ridershp/#A1, "Transit Agency Data," "APTA Ridership Reports," "Mode Totals."

Notes
a Transit passenger trips include heavy rail, light rail, commuter rail, trolleybuses, buses, aerial tramways, automated guideways, cable cars, ferryboats, inclined planes, monorails and vanpools.
b APTA defines unlinked passenger trips as: "the number of passengers who board public transportation vehicles. Passengers are counted each time they board vehicles no matter how many vehicles they use to travel from their origin to their destination." See: http://www.apta.com/research/stats/ridershp/definitions.cfm.



1.5 *Trends in Water Use, United States, 1950–1995 (latest dates available).*
Source: Graphed from figures provided in US Geological Survey (USGS). Online. Available at: http://ga.water.usgs.gov/edu/tables/totrendbar.html (accessed December 5, 2003) and Solley, W.B., Pierce, R.R. and Perlman, H.A. (1998) *Estimated Use of Water in the United States in 1995*, Denver, CO: US Geological Survey, Table 1, p. 7.

infrastructure are at least a decade and often a century or more. Some examples of these design lifetimes are given below:

- *Roads:* 20 years, but depends on condition standard, type of traffic, and roadway materials (Marland and Weinberg 1988: 328)
- *Bridges:* variable, hundreds of years (Marland and Weinberg 1988: 328)
- *Buses:* 8–15 years (Armstrong-Wright 1986: 32)
- *Light rail:* 25 years (Armstrong-Wright 1986: 32)
- *Rapid rail:* 30 years (Armstrong-Wright 1986: 32)
- *Power plants:* historically, 25–30 years; a 70-year design standard is used in Russia (Marland and Weinberg 1988: 328)
- *Dams:* variable, hundreds of years (Marland and Weinberg 1988: 325)
- *Water and wastewater treatment and distribution systems:* 15–100 years, depending on the component (US EPA 2002: 11, Table 2-1, see compilation in Chapter 5).

These trends and conditions highlight the significant changes associated with the upgrading (including technological upgrading) of our infrastructures in the developed regions of the world. As illustrated in Chapter 10, the situation in the developing world is equally if not more daunting. Throughout Asia, Africa, and Latin America, local governments are struggling to provide basic infrastructure for economic and community growth. The challenge in this case is to conceive of a means for the innovative (e.g. low-cost) use of technology as part of the general investment strategy for improving infrastructures in these regions.

IT Growth and Technological Changes

A key factor affecting the integration of IT into infrastructure (whether in developing or developed regions) is a set of trends that make IT more affordable, reliable, and powerful than could have been imagined a few short decades ago. These conditions include the rapid growth in product use and technological changes in terms of the exponential growth in processing power and IT capacity.

Product Use and Byproducts

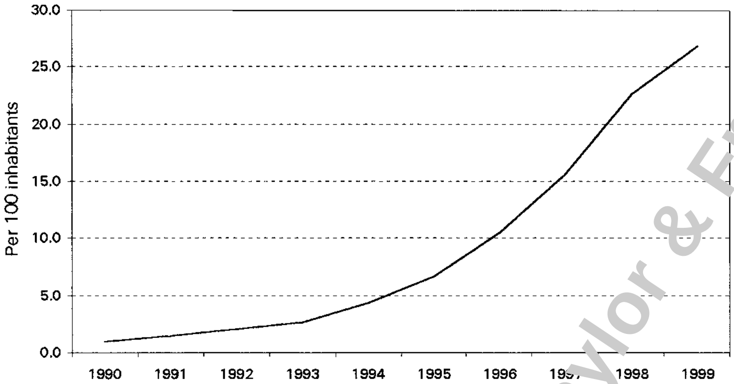
IT products and services are numerous and highly diverse. The use of some of the more common ones show dramatically high growth rates.

- Mobile cell phone use continues to rise. In 1990, the OECD reported a total of 10,537,234 mobile cellular subscribers among Organisation for Economic Co-operation and Development (OECD) countries with about half (5,283,055) in the US By mid-1999 this number had grown to 292,780,578 (OECD 2000: 73). This amounts to a penetration rate on average for all OECD countries from one per 100 inhabitants in 1990 to 26.8 by June 1999 (National Science Board 2002: Appendix Table 8-3), as shown in Figure 1.6.

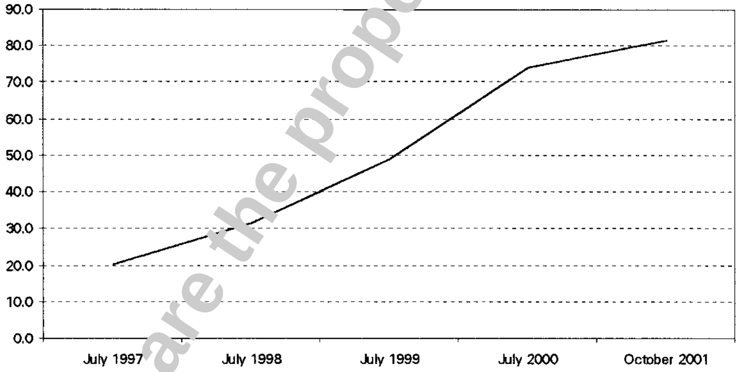
- Internet use continues to rise. Over a four-year period between 1997 and 2001 the number of Internet hosts that house, for example web sites, quadrupled in the US (see Figure 1.7). Access to the Internet continues to grow and by the end of 2002, 60 percent of Americans were reported to have Internet access (Horrigan and Rainie 2002).

- High-speed broadband use continues to rise. By 2003, 16 percent of Americans had access to high-speed broadband service, a dramatic rise in those with access since 2000. In other countries, like South Korea and Canada, the rise in access is reported to be even higher with over half of the households with high speed broadband connections (Horrigan 2003: 1–2).

Not only has growth in products been widespread, but the growth in waste accumulated has also occurred, reflecting product expansion. According to the National Safety Council (Itasca, IL), “500 million US computers are estimated to become obsolete by 2007” (Irrinki 2000: 33). Assuming 200 million phones in



1.6 *Average Mobile Phone Use Penetration, OECD Countries, 1990–1999.*
Source: Graphed from National Science Board (NSB) (2002) *Science & Engineering Indicators – 2002*, Volume 2: Appendix Tables, Arlington, VA: National Science Foundation (NSB–02–01). Appendix Table 8.3, Page A8–3, Online. Available at: http://www.nsf.gov/sbe/srs/seind02/append/c8/at08-03.pdf. Courtesy of the National Science Foundation. A similar graph appears in Volume 1, Figure 8–5, p. 8–8 as growth in mobile phone subscribers. Data source in NSB tables is: Organisation for Economic Co-operation and Development (OECD) (2000) Cellular Mobile Pricing Structures and Trends, Paris.

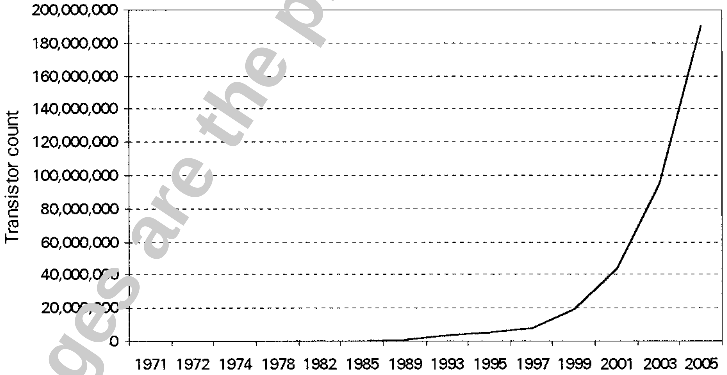


1.7 *Average Internet Hosts per 1,000 Inhabitants, OECD, 1997–2001.*
Source: Graphed from National Science Board (NSB) (2002) *Science & Engineering Indicators – 2002*, Volume 2: Appendix Tables, Arlington, VA: National Science Foundation (NSB–02–01). Appendix Table 8.4, Page A8–4, Online. Available at: http://www.nsf.gov/sbe/srs/seind02/append/c8/at08-04.pdf. Courtesy of the National Science Foundation. Data source in NSB tables is: Organisation for Economic Co-operation and Development (OECD) (2000) Cellular Mobile Pricing Structures and Trends, Paris. Data from Netsizer http://www.netsizer.com.

circulation for 1.5 years each, Fishbein has estimated that about 130 million phones would be retired per year (Fishbein 2002: 22). Beyond concerns over waste accumulation are the broader social conditions associated with environmental influences of products and materials across the entire sequence of IT activities (Richards *et al.* 2001). Concerns about the toxic materials in IT products and equipment have identified nanotechnologies as a source of environmental pollution, which has initiated major governmental research on the topic (Masciangioli and Zhang 2003: 106A–7A).

Technological Changes

Technological changes in the equipment used for IT have enabled the speeds for data processing to increase, and hence the capabilities for infrastructure. These changes have depended upon breakthroughs in the composition of various processing components expressed primarily in terms of chip capacity. Chip capacity, in terms of the density of transistors on a chip, continues to grow. “The number of transistors on a chip has doubled approximately every 12 to 18 months for the past 30 years – a trend known as Moore’s Law . . . named for Gordon Moore of Intel, who first observed it” (National Science Board 2002: A8-1). This rate of growth is shown in Figure 1.8. “The number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented” (Webopedia 2001). The National Research Council (1998: 9) notes further that, “Combined with numerous other technological advances, this capability has led to a doubling of microprocessor power every 18 months.” Because of the limits imposed by silicon-based film, it was thought that chip density was approaching a limit, however, recent advances in nanotechnology may enable Moore’s Law to continue to operate (Keren *et al.* 2003).



1.8 *Moore’s Law, 1971–2005.*

Source: Graphed from National Science Board (NSB) (2002) *Science & Engineering Indicators – 2002*, Volume 2; Appendix Tables, Arlington, VA: National Science Foundation (NSB–02–1), Appendix Table 8.1, Page A8–1, Online. Available at: http://www.nsf.gov/sbe/srs/seind02/append/c8/at08–01.pdf. Courtesy of the National Science Foundation. A similar graph appears in Volume 1, Figure 8–1, p. 8–5 (log scale). Data sources in NSB tables is: 1971–01 – Available at http://www.intel.com/pressroom/kits/quickrefyr.htm; 2003–05 – International Technology Roadmap for Semiconductors. 2000 International Technology Roadmap for Semiconductors, available at http://public.itrs.net/Files/2000UpdateFinal/ORTC2000final.pdf.

Data storage mediums are also changing rapidly. Over a period of two decades or so, storage has changed from magnetic tape, to diskettes, to CDs, to DVDs, with associated hardware changes. Programs and associated software have changed rapidly as well.

All of these changes have created a situation where infrastructure systems have had to constantly adapt and retrofit IT to their operations at a rate that is typically faster than the usual time period for rehabilitating infrastructure. These differentials raise questions about the potential for increasing very formidable cascading failures due to increased infrastructure interdependencies discussed earlier in this chapter.

Integration

As alluded to in our conceptual model for managing digital infrastructure, these rapid technology developments and the potential for increasing cascading effects need to be considered within the systems domain of infrastructure and its users. While the technological advancements are impressive, the most pressing challenge is the need to harness IT in a manner that produces social, economic and community gain from infrastructure systems. As a society we have come to value the day-to-day service levels of a modern infrastructure. The roads we travel upon, the water we drink, the phone calls we make, the Internet we surf, the lights we turn on – all of these functions have become increasingly reliant on reliable IT systems. To this end, this book is about harnessing the power of technology to deliver these day-to-day services in a socially responsive, economically efficient, environmentally responsible and, yes, secure manner. While aware that things do indeed "bite back," the premise of this book is that technology can be harnessed to benefit our quality of life.

Organization of this Volume

Part I of the book gives three key dimensions of the IT and infrastructure issue, namely, technology, management, and policy. As the workshop noted above featured, it is in these contexts that IT and infrastructure co-exist and are constrained or enabled. Chapter 2 opens with technology, since in order to make informed decisions about new infrastructure systems, professionals and managers need to understand the fundamentals of the technology. Chapter 3 follows with the management of the technology, since the reconciliation of infrastructure complications, technological developments and policy choices and tradeoffs arrives at the doorstep of infrastructure managers. This chapter both provides a conceptual model for managing digital infrastructures and grounds this model in a series of case analyses from different infrastructures in diverse parts of the world. The last chapter in this section, Chapter 4, deals with policy. The infrastructure manager operates in a policy environment, which can condition, impinge or facilitate the decision making process. This chapter analyzes the policy environment, noting the state of policy with respect to integrating IT and infrastructure.

Part II provides an in-depth examination of the experiences within specific infrastructure sectors in incorporating IT – water, transportation, electric power, and telecommunications – to learn how those infrastructure systems are adapting to IT, and whether the different sectors share common experiences.

Part III enlarges the perspective on the IT/Infrastructure issue with four cross cutting analyses. The first analysis considers the economic implications of the convergence of IT and infrastructure, providing an empirical foundation for the investment context surrounding digital infrastructures. The second analysis considers the global context for digital infrastructures, with a focus on the emerging conditions in developing regions of the world. The third provides extensive examples and insights in the use of IT to enable new green technologies for infrastructure services within buildings. The fourth analysis places digital infrastructures in a broad environmental and philosophical perspective, suggesting how technology can play an integral role in devising environmentally responsive programs and policies. The concluding chapter takes up additional cross-cutting issues identified in the earlier chapters and related literature, and provides new directions. These themes and directions include the importance of understanding digital infrastructure interdependencies, the need to learn from extreme events involving digital infrastructures, the challenge of designing digital infrastructures that can be understood and used by diverse end-users and organizations, educational needs to support all of this, and, finaly, the need to consider digital infrastructures as part of a global concern for development and sustainability.

Throughout these sections, the chapter authors strive to balance the general principles of IT and infrastructure with practical experiences and innovations. While the general tone does lean toward the optimistic, each chapter confronts the complexities of the subject matter including the many crises and breakdowns that can confront civil and environmental infrastructures. Society has made great strides in its use of IT, and this volume focuses on extending that achievement to the area of civil and environmental services.

Notes

1 The Domain Name System (DNS) is "a distributed database that keeps the name-to-address mappings for the Internet" (National Research Council 2002b: 4-1).

2 The workshop, was held in June 2001 in Arlington, VA by the Institute for Civil Infrastructure Systems (ICIS) (www.nyu.edu/icis) located at New York University's Wagner Graduate School of Public Service, which is a National Science Foundation (NSF) funded consortium of four universities: NYU, Cornell University, Polytechnic University of NY, and the University of Southern California. The workshop brought together about fifty participants from government, industry, and academia who are specialists in IT, infrastructure or both. Short papers prepared by the participants and keynote addresses by Professor William Mitchell of MIT, Dr Joseph Bordogna, Deputy Director of the National Science Foundation, and Dr Braden Allenby' Vice President of Environment, Health and Safety of AT&T. The full report of the workshop was prepared by Zimmerman, Gilbertson and Restrepo (2002) and is located at: www.icisnyu.org/admin/files/FinalITreport3.pdf.

3 Organisation for Economic Co-operation and Development (OECD) (2002) "Measuring the Information Economy 2002," pp. 81–3, Online. Available at: www.oecd.org/dataoecd/34/37/2771153.pdf (accessed January 16, 2004).

4 Telecommunications is defined in the American Heritage Dictionary (2000) as “the science and technology of communication at a distance by electronic transmission of impulses, as by telegraph, cable, telephone, radio, or television” and as “the electronic systems used in transmitting messages, as by telegraph, cable, telephone, radio, or television,” and to connote “a message so transmitted.” The American Heritage Dictionary of the English Language, Fourth Edition (2000) Boston, MA: Houghton Mifflin Company. dictionary.com, Online. Available at: dictionary.reference.com/search?q=telecommunications (accessed December 10, 2003).

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