Journal of the Association for Information Systems

Volume 10
Issue 5 *Special Issue on e-Infrastructure*

Article 6

5-28-2009

Introduction: An Agenda for Infrastructure Studies

Paul N. Edwards
University of Michigan, pne@umich.edu

Geoffrey C. Bowker
University of Pittsburgh, gbowker@scu.edu

Steven J. Jackson
University of Michigan, sjackso@umich.edu

Robin Williams
University of Edinburgh, R.Williams@ed.ac.uk

Recommended Citation

Edwards, Paul N.; Bowker, Geoffrey C.; Jackson, Steven J.; and Williams, Robin (2009) "Introduction: An Agenda for Infrastructure Studies," *Journal of the Association for Information Systems*, 10(5), .
DOI: 10.17705/1jais.00200
Available at: https://aisel.aisnet.org/jais/vol10/iss5/6

Journal of the Association for Information Systems

JAIS

Special Issue

Introduction: An Agenda for Infrastructure Studies

Paul N. Edwards
School of Information
University of Michigan
pne@umich.edu

Steven J. Jackson
School of Information
University of Michigan
sjackso@umich.edu

Geoffrey C. Bowker
School of Information Sciences
University of Pittsburgh
gbowker@scu.edu

Robin Williams
Institute for the Study of Science, Technology and Innovation
University of Edinburgh
R.Williams@ed.ac.uk

Volume 10, Special Issue, pp. 364-374, May 2009

Introduction: An Agenda for Infrastructure Studies

1. Introduction: An Agenda for Infrastructure Studies

As with many special issues, this one has had a long history, traversing multiple infrastructures. Email, electronic banking, planes, trains, and automobiles got us to a workshop in Michigan in 2006, at which three of us were approached to produce a special issue of JAIS. The editor told us (even in the age of the Internet, word of mouth works wonders) of a similar workshop hosted by Robin Williams in Edinburgh, so we joined forces. What results is a special issue that brings together leading scholars in the emergent field of infrastructure studies — authors whose collective insights sketch out the vitality of, and lay the groundwork for, this field.

2. Imagining Infrastructure

During the last two decades, the term "infrastructure" has spread virally through journalism, government, MIS, and academia. Used in a vast variety of senses, the word often (but not always) connotes big, durable, well-functioning systems and services, from railroads and highways to telephone, electric power, and the Internet. In the 1990s, the "information superhighway" metaphor deliberately coupled the older hardware of urban civilization to rapid digital convergence. At this writing (2009), in the midst of the worst economic crisis since the Great Depression, infrastructure projects dominate economic stimulus proposals; repairs to aging bridges and roads compete intensively with investments in renewable energy sources and electronic medical records. Infrastructure today seems both an all-encompassing solution and an omnipresent problem, indispensable yet unsatisfactory, always already there yet always an unfinished work in progress.

In science, calls for new cyberinfrastructure (as it is known in the USA) and e-science (as it is called in Europe) to support data sharing and new interdisciplinary approaches have led to significant new funding for network-based services such as grid computing, data federation, and community building. The UK spent £275 million to promote e-science from 2001to 2006 (with a similar sum devoted to upgrading its computer and network equipment, as well as large investments particularly in biology and environmental sciences). In 2005 the US National Science Foundation (NSF) established a cross-directorate Office of Cyberinfrastructure, spending some $175 million annually to promote new projects throughout the natural and social sciences as well as to keep older ones, such as the colossal TeraGrid (teragrid.org), rolling. E-infrastructure also encompasses emerging forms of e-commerce such as RFID product tracking or online marketplaces, and related work in vertical infrastructure standards. As ever with infrastructures, however, the challenges far exceed the commitments. Despite the recent surge in awareness, infrastructure, in general, lacks visibility, symbolic value, and short-term payoff. Few in the public know, for example, that New York City Water Tunnel No. 3 is the largest engineering project in the city's history and one of the most complex engineering feats in world history.

But is e-infrastructure truly infrastructural? Are e-infrastructures really something different from information systems, the central concern of this journal and the Association for Information Systems itself? Perhaps e-infrastructure is merely a buzzword, just another in a long line of phrases from systems management (1960s) to knowledge networking (1990s) to enterprise management systems (2000s) — notional terms often deployed to assert understanding and control over systems that have invariably proved far more unruly in practice than on paper or in the imagination of their designers, builders, and managers. Similarly, the NSF, like other research funding agencies, cycles through new buzz phrases about once every five years, most recently from digital libraries (early 1990s) to collaboratories (late 1990s) to cyberinfrastructure (early 2000s).

We cannot disagree entirely with this jaded assessment. Yet we also think that the concept of e-infrastructure captures several major changes of the last two decades. First, information handling in many areas has shifted decisively from individual computers and local networks to more distributed grid or cloud paradigms dependent on ubiquitous links to and through the global Internet. Second, digital convergence is rapidly integrating most media, melding data processing and text editing with audio, video, and images. Finally, the World Wide Web has become a *sine qua non* of commerce, government, and social life across much of the world. These phenomena mark the beginning of a transition to genuine infrastructure: robust, reliable, widely accessible systems and services that are beginning to look in form and centrality like the digital equivalents of the canonical infrastructures of telephony, electricity, and the rail network — a resemblance scarcely credible even two decades ago.

Yet despite all this, in many respects and settings, localized information systems and individual computers remain the norm. Digital convergence is far from complete, and even the Web remains, by many measures, something like an infrastructure-in-waiting. For example, while finding some information resources online has become a trivial task, finding many others can still prove maddeningly difficult — and finding is only the first step. A colossal cacophony of differing data formats, access methods, security systems, and intellectual property restrictions still places us very far from the universal libraries and information utilities of visionaries from Paul Otlet and J.C.R. Licklider to Brewster Kahle and Tim Berners-Lee. Today's situation can be compared to electric power in early 20th century London, when the city had "65 electrical utilities, 70 generating stations..., 49 different types of supply systems, 10 different frequencies, 32 voltage levels for transmission and 24 for distribution, and about 70 different methods of charging and pricing" (Hughes, 1983). Nor are we much (or any) nearer to the utopian visions that have often accompanied such universalist dreams: though it has lowered many barriers, the web has not created a "flat world" of seamless and inclusive social exchange, and it shows few signs of doing so anytime soon. (Even as we introduce dial-up modems in some parts of the world, we have a voracious appetite for bandwidth in others — to the extent that mobile phones in the developing world offer a different kind of infrastructure competing directly, in some respects, with the Internet).

These remarks raise the crucial question of scale. How big, or deep, or old, or widespread does something have to get before it becomes infrastructure? Even if we could answer this, how would we measure or simply think about such variables — by geographic reach, number of people served or involved, amount of data transmitted, criticality (or "can't-do-withoutness") of the service? Partly, this is the old philosophical question of when a collection of bits of grit becomes a sandpile, or the elusive tipping point at which quantitative change morphs into qualitative change. After all, most physical highways connect in some way to cul-de-sacs, dirt roads, and abandoned pathways. E-infrastructures on the colossal scales of Licklider's "intergalactic network" or Kahle's "Library 2.0" may never fully arrive. But that is the wrong scale to look at — especially now, still relatively early in the build-out process, which for other infrastructures typically required around half a century (Grübler, 1996). Perhaps e-infrastructure is emerging first on smaller scales of time, space, and service, as second-order systems built on top of and around the Internet and other existing information frameworks.

These e-infrastructures are built to order for firms, governments, or scientific enterprises, and they are often directed toward particular, rather than, generic purposes. These are the scales addressed by the five articles in this special issue. They span a wide range of services, national contexts, and information environments. They include medical information networks in India and the UK; a Microsoft SharePoint installation connecting an oil company's 25,000 employees; four US scientific cyberinfrastructure projects in varying stages of development; and a project to link legislative processes in a state government with those of the federal government in Germany. They treat different scales and types of organization, from firms to scientific research enterprises to state and national government.

The articles in this special issue focus on these smaller scales, but they are relevant to the larger ones as well. They probe how actors cope with central problems of e-infrastructure: how to integrate or replace existing systems; how to handle local divergence from a desired norm, including how (or whether) to keep users from working around or outside the system; and what is gained and lost in the transition to a new infrastructure. They bring us below the surface level of goals and implementation, into the murky depths of tension, failure, and compromise where conflicting purposes and political differences meet technical details. An underlying theme in all the articles is that any new infrastructure must somehow integrate with an installed base that includes not only artifacts but human habits, norms, and roles that may prove its most intractable elements. Because new infrastructures often shift power relationships, they may also encounter resistance from unexpected quarters.

Many of these integration issues revolve around the gateway problem we identified, in earlier work, as crucial to the move from isolated systems to genuine infrastructure (Edwards, Jackson, Bowker, and Knobel, 2007). In general, new infrastructures begin with a system-building phase in which a firm or other entity conceives an end-to-end solution to some problem: an isolated system, centrally designed and controlled by the builder. Success brings competition, not necessarily in the marketplace, but in the form of alternative systems created by other entities. At some point the competition is resolved either by one system beating out all the others (the rare case), or by the creation of "gateway" technologies or social arrangements that permit multiple systems to interoperate (the common case). Because of the relative ease with which they can be constructed in software, gateways are among the most common mechanisms by which information infrastructures evolve, but even so, seamless interoperability very often remains elusive. Gateways permit multiple systems to be used as if they were a single integrated system, though rough patches often remain that must be smoothed over by user action.

Google Scholar, for example, functions as a gateway between electronic journal publishers, university libraries, digital books in Google Book or the Hathi Digital Trust, and individual researchers. Between identifying a desired article or book and successfully viewing full text on their screens, however, users must often take several steps on their own as they traverse various boundaries among the many different databases and access systems involved — as many readers of these pages will no doubt understand, all too well, from their own experience. Often, individual libraries and even individual researchers build their own, customized gateways to smooth the integration. (The University of Michigan library, for example, built a Firefox add-on for searching its own catalog. One of the authors of this introduction then constructed another Firefox add-on to search Google Scholar directly within the university library proxy, achieving better journal-search integration than the official university Firefox add-on, and distributed the add-on locally.) Some of the thorniest problems are not technical but legal and economic; for example, until lawsuits over copyright permissions are resolved, the vast number of books already scanned into the Hathi Digital Trust library can be searched, but no text can be displayed from books still under copyright.

In "The Long Now of Infrastructure," Ribes and Finholt report findings from ethnographic studies of four scientific cyberinfrastructure projects in the earth and environmental sciences. Ranging in scale from institutions to work organization to relatively local enactments of technology by individuals and small groups, they identify a series of tensions encountered and often strategically exploited by actors involved in the building, using, and managing of new infrastructure: for example, how to motivate contributions (of data and effort) to the project; how to align the end goals of an often diverse collection of developers, funders, and potential users; and how to move beyond prototypes to operational, maintainable, robust infrastructures.

One such alignment problem can be seen in the differing interests of domain (biology, physics, etc.) scientists and computational scientists (software, hardware, etc.) in the design of e-infrastructure. For the former, stability and sustainability may be key; experimental systems that crash and burn may threaten the viability of long-standing domain science programs (and the careers of the people who develop them). For the latter, innovation and research contributions “countable” within the field come precisely from the design and testing of novel and, therefore, risky systems; in such a world, the development of solid and sustainable production-grade systems holds little reward — and to the extent that academic grant and promotion criteria undervalue such work, may actively threaten or limit the career trajectories of researchers doing such work. If finding projects or partnerships that merge these interests in effective and mutually beneficial ways is difficult in general, it only gets harder over time. As experimental prototypes give way to stable and operational systems, the true possibilities for domain contribution are likely to peak, while those for ongoing computational innovation begin to decline. Thus, just as projects are coming into their own in domain terms, the computer scientists may be halfway out the door. This tension is reflected in a long-standing and by now painfully familiar problem in the funding of scientific infrastructure, in which funds for developing flashy new systems are relatively easier to come by, but ongoing money for maintaining operational systems (the workhorses of domain science) is in vanishingly short supply.

In "Configurable Politics and Asymmetric Integration: Health e-Infrastructures in India," Sahay, Monteiro, and Aanestad study an effort to link two previously unconnected health information systems in the Indian state of Gujarat. "Integration," as they point out, "seems crucial for evolving infrastructures; however, there is little consensus on what it entails." This a sterling example of the gateway problem. The starting point for "Configurable Politics" is that initial choices in developing and extending large scale (health) information systems both establish a planned technical configuration and, at the same time, select and configure together an array of social and political actors: the eponymous "configurable politics." Arranging and choosing which players are involved — and how — creates long-term implications for the unfolding and success (or otherwise) of the venture. Configuring, in this sense, represents a strategic approach to creating a gateway, one which may take the form of assembling and enrolling individual and institutional actors as well as technical means, much as described by actor-network theory (Latour, 1987, 1996, 2005; Law, 2003). Though the paper is written from the point of view of an external non-commercial group wishing to develop open source solutions for health infrastructures, the asymmetry the authors observe between the positions of central and peripheral players would also pertain in a modified way to external commercial providers.

Ure et al., in "The Development of Data Infrastructures for eHealth: a Socio-Technical Perspective," document the tensions and challenges confronting efforts to share data across and within disease domains associated with a variety of UK HealthGrid projects. As argued by the authors, these tensions can rarely if ever be isolated and resolved at a purely technical level (despite amazingly persistent dreams and efforts to the contrary). In the context of eHealth — and, we would argue, many other fields — the deep heterogeneity (social, organizational, and technical) of local action, the inevitable practical embedding of data, and the thick and distinctive histories constituting epistemic practice and culture in health-related domains works against any simple semantic or technical fixes for coordination problems between projects and fields. This has led to a variety of strategic responses, ranging from one-size-fits-all integration efforts built on common ontologies, to more dynamic and flexible user-tailored strategies inspired in part by Web 2.0 and social software applications. While the UK HealthGrid projects provide no clear and universal answers to these questions, they do suggest the importance of thinking the social and technical together. In the eHealth world, as elsewhere, winning strategies are most likely to be found precisely at the confluence of technical and organizational practice.

A broadly parallel story can be found in Hepsø, Monteiro, and Rolland's "Ecologies of e-Infrastructure," set this time around efforts to deploy a new Microsoft SharePoint e-Infrastructure in the pseudonymous “NorthOil,” a multinational oil and gas company. Driven by post-Enron concerns around accounting and transparency, together with the long-standing problem of aligning knowledge across the various expert sets associated with the discovery, optimization, and efficient exploitation of mineral assets, SharePoint was to have solved many problems at once, while overcoming a legacy of fractured information management within the company. This “mono-cropping” vision, however, quickly ran into difficulties. SharePoint installation at NorthOil has struggled to replicate and supplant both the specialized systems that have grown up in various professional and organizational niches within the company and the patches and compromises (we might call these gateways) that have been worked out to move between them. Lest this be read as yet another heroic resistance story celebrating the stubbornness or stickiness of local practice, the authors are quick to point out that the move to SharePoint *has* brought changes to informational and organizational practice at NorthOil — though not usually or directly those predicted by SharePoint's champions within the company. The story of infrastructural change at NorthOil, argue Hepsø et al., is about the working out of a central and complex tension: “between implicit and explicit top-down demands for tight integration embedded in the SharePoint eInfastructure and how these unfold dynamically against the persistent, bottom-up reliance on niche systems and micro-practices of commensurability.”

In "Infrastructuring: Toward an Integrated Perspective on the Design and Use of Information Technology," Pipek and Wulf present results from a long-term study of information systems and work processes developed to link legislative processes in a German state government with those at the federal level. Their analysis of infrastructuring rests on three key moves.

First, they introduce the concept of "work infrastructure," essentially the full set of systems and practices employed by any given work group. With respect to information systems, work infrastructure includes only what users actually use and how they use it, rather than the full range of facilities available to them, which they have either chosen not to adopt or failed to become aware of. Further, it will include locally-developed workarounds, shortcuts, and combinations of systems and practices — gateways — never imagined by system designers. Second, based on this concept of work infrastructure, Pipek and Wulf abandon the traditional distinction between IS designers and users. They point out that any actual work infrastructure includes numerous user innovations, and that designers — focused on meeting requirements for some set of work tasks — rarely if ever take full account of the full panoply of systems and practices involved in local accomplishing of work goals. Finally, they describe a "point of infrastructure" centered on a temporary breakdown in a work infrastructure's actual or perceived ability to provide services. At this point of infrastructure, normally invisible elements of the work infrastructure may become salient for actors present in the situation, regardless of whether they are professionally trained as IS designers. This moment catalyzes "in-situ design work," both informal and formal, by both designated designers and users, that reconfigures and/or extends the existing work infrastructure to repair the breakdown. This process recurs periodically when breakdowns occur, producing waves of in-situ design and redesign punctuated by periods of stability when the work infrastructure fades into its normal background state of invisibility.

Pipek and Wulf further argue that a wide variety of work practices — tasks, routines, and praxis — prepare both users and professional designers for these points of infrastructure. "Work development activities" aimed at supporting the work process include formulating the work process itself as well as learning about and using existing systems. Thus, experience-based culture and background knowledge are created that are then called forth during in-situ design work following a breakdown. Meanwhile, on the IS design side, technology standards and design culture and practices are developed. "Infrastructural background work" may include longer-term technology development efforts responding to previous breakdowns. Pipek and Wulf then articulate these principles further in the context of four brief case studies. As they put it, their strong and subtle framework takes an important step toward "bridging the gap between technology development and appropriation."

In earlier work, we argued against the idea that infrastructures could be "built," at least in the usual sense of "deliberately designed and constructed to a plan" (Edwards et al., 2007; Jackson, Edwards, Bowker, and Knobel, 2007). We promoted, instead, the metaphor of "growing" an infrastructure, to capture the sense of an organic unfolding within an existing (and changing) environment. We made this argument because the history of most large-scale infrastructures includes two crucial moments. One is a gateway phase, discussed above, in which technical, political, legal, and/or social innovations link previously separate, heterogeneous systems to form more powerful and far-reaching networks. The other is a recurring issue of adjustment in which infrastructures adapt to, reshape, or even internalize elements of their environment in the process of growth and entrenchment. These are also the points at which most systems fail to become infrastructures: they cannot successfully link with other systems, adapt to a changed environment, or reshape or internalize elements of the environment in order to grow and consolidate. A principal reason most systems fail is that these critical moments are difficult to anticipate or plan for, and rarely lend themselves to deliberate design.

Ribes and Finholt's ethnographic studies of cyberinfrastructure projects further illustrate this tension. Would-be infrastructure developers gain funding by claiming revolutionary potentials. Yet in practice, they immediately become caught up in short-term design issues, principally those of interest to computer and information scientists as research problems. To make the transition successfully into production mode — providing a basic service to a scientific community — they must adapt over a period of years to a changed environment, especially as regards funding for ongoing development and maintenance. Most projects fail to leap this hurdle, instead falling into disuse at the prototype phase. Those that do succeed may indeed transform scientific practice, but rarely in exactly the way they had planned, and often at the cost of adapting their goals to those of a new set of funders. In our terms, they rarely if ever "build" infrastructure; they must nurture it and, if they are lucky, help it to grow.

Additional arguments against the building metaphor are supplied by Pipek and Wulf, who argue that standard design approaches to workplace information systems rarely reach the deep levels and broad perspectives necessary to fit new systems into existing work infrastructures, precisely because any genuine infrastructure is mostly invisible. As a result, traditional designers work within a depressingly limited conception of tasks, requirements, and users themselves, with predictably disappointing results. Pipek and Wulf's alternative notion of "infrastructuring" turns this story on its head. Rather than picturing infrastructure after a simple build-and-serve model, they see infrastructure as a transitive verb (much as John Berger once argued that "to underdevelop" is transitive). Once this switch is made, new moments in infrastructural development and new kinds of work come into view. Fiber optic cables get laid along with the social, organizational, and institutional arrangements that make them possible (and sustainable). Trains run on tracks other than those laid in steel. To paraphrase Woodrow Wilson on democracy, infrastructure lives in a world made safe for infrastructure.

Collectively, these articles constitute powerful evidence against the sort of lingering functionalism that continues to mark efforts to build, but also too often to <u>understand</u>, infrastructure. They also suggest the central lines (and wicked problems) of the necessary field of infrastructure studies. What might such an endeavor look like? In the remainder of this introduction, we argue that bridging three kinds of scales — global/local, large/small, and long-term/short-term — present central challenges with which any effective practice and theory of infrastructure must come to terms.

3. Bridging Scales in e-Infrastructures

We have already mentioned the issue of scale with respect to size. Commonly, discussions of scaling infrastructure refer to making systems bigger or extending their reach. Behind every system builder's ambition stands the hope of network effects, in which utility increases exponentially with the number of users: a system with thousands of users might be worthwhile, but a system with millions of users is an industry, and one with billions of users — like the global telephone network or the Internet itself — becomes obligatory. While these effects are real and important, the focus on scaling <u>up</u> detracts attention from the equally significant issue of scaling <u>down</u>, i.e., making global infrastructures locally useful.

The ethnographic approach taken by most of this special issue's papers reveals why this question should be central in infrastructure studies. Even if we think only of information infrastructure, rather than the full panoply of shared systems and services, the <u>actual</u> infrastructures of people's real work lives always involve particular configurations of numerous tools used in locally particular ways. Some tools, such as the Web, have global aspects, but others, such as electronic forms, courseware, calendaring, and other systems, may be locally created or configured. Anyone coming into a new workplace has to learn, through engagement, which of the potentially available elements constitute the local infrastructure and how it actually works. Most of the articles in this issue treat aspects of this process, which often involves locally constructed gateways to globally available systems. Further, as most of these articles also show, they involve constructing gateways among various local systems and work practices. While these gateways may be "located" in an apparently global system like the Web, their actual use is frequently entirely local, dependent upon and linked with local work flows and communities of practice. Following, describing, and mapping these bridges among various scales of infrastructure demand techniques of analysis that penetrate deeply into the work lives of organizations and individuals, rather than uncritically accepting the largest scales of infrastructure as the most important ones.

Another crucial scale is temporal. Ribes and Finholt conceptualize a "long now" of infrastructure. By this they mean that their informants (participants in scientific cyberinfrastructure projects) experience an expanded or multi-dimensional time horizon, in which immediate problems and tactical maneuvers need to be addressed simultaneously with strategic goals and potential future alignments. Participants seek both to articulate and to resolve the tensions produced by this long now. To succeed in doing so, they must gain a sophisticated perspective that integrates different levels of work, organization, and motivation.

This presents a dramatic paradox for any attempt to design an infrastructure, especially in the contemporary world — suspicious as we have become of grand modernist planning and the baroque institutions that such planning has always seemed inescapably to engender. The paradox is this: visions for new e-infrastructures always imagine them as "future proof" and universal, yet real-world systems are always future-vulnerable and particular. Designers dream that they will cater not only to diverse communities, users, and uses in the present, but also to future communities, users and uses not yet anticipated (Edwards, 1998, 2002).

Some e-infrastructures, such as health and environmental databases, need to remain in place over very long periods — the lifetimes of human beings, or the century-to-millennium scale of climate change and epidemic diseases — or risk dire consequences for knowledge and human welfare. However, despite developers' best attempts to hedge against future needs and variability, their attempts at transcendence inevitably remain lumpy, partial, and incomplete. Today's universal solution will, on some not too distant day, become tomorrow's quaint and inflexible legacy system. Spanning scales in time proves, if anything, even more difficult than spanning global/local and small/large.

4. Negotiating e-Infrastructures

E-Infrastructures can be seen as negotiated in (at least) two senses, which give emphasis, respectively, to process and outcomes: first in the sense of encounters and accommodations between competing actor priorities, and second in the sense of the constitution of an evolving landscape around which actors must negotiate.

The first point revolves around the finding that that there is no "correct" solution for building new eInfrastuctures. Instead, those involved must grapple to make the most appropriate trade-off between a number of goals that may be more or less in conflict (e.g., between catering to specific local needs and meeting larger community goals, or between short-term and potentially evolving longer-term requirements). In the past this state of affairs has often been reflected in a debate between the universalist and modernist claims of system builders attempting to build solutions that can cater to all current and future needs, and critical accounts of what is actually achieved as inevitably bounded within particular historical and social settings. However, contemporary scholarly analyses of e-Infrastructures, and the papers in this collection, are striving to go beyond this dichotomised debate in two ways. They highlight the contradictions and tensions surrounding the emergence and growth of infrastructures — with the associated risk of undesired unplanned side-effects (Hanseth, Jacucci, Grisot, and Aanestad, 2006) —and then go on to focus on the emergent strategies by which the involved actors seek some practicable accommodation between these contradictory concerns and exigencies in creating workable solutions, which can, for example, bridge across a range of differing sociotechnical settings (Williams and Pollock, 2009).

The second point has to do with the nature and style of conflict as an ever-present feature of infrastructural life, particularly, though not exclusively evident, in its moments of formation. As each of the cases in the present issue makes clear, infrastructure is a powerful phenomenon, shifting organizational routine, practice, capacity, and in some cases, the life chances of groups. This gives the development of infrastructure a powerfully (re)distributive function, shifting (or in some cases conserving) resources and potentialities for action. This can work in multiple directions. As infrastructure grows and locks in, individuals and groups may find their room for maneuver expanded: Here, the emerging infrastructure affords new choices and possibilities and the agency, power or standing of these groups may be subtly and not-so-subtly enhanced. Conversely, groups that start on what Doreen Massey has called the "receiving" end of infrastructure may end up even more so — that is, still more constrained in effective choice and action, with their freedom of maneuver still further reduced or devalued (Massey, 1993). As with other features of infrastructure, such dynamics can be mapped at multiple scales, from the individual worker cut in or cut out by the implementation of a new technical system, to the reordering of professional work and hierarchies (for example, Star and Bowker's work on nursing classification systems (Bowker and Star, 1999) and Ina Wagner's study of hospital time management systems (Wagner, 1993), to the effective destruction or sidelining of whole categories of work and their associated forms of life through infrastructural change. Grand historical examples of this include the effects of mechanization on American farm labor in the 20th century, or the British textile industry in the 19th. Such dynamics constitute a deep politics of design, running beneath and beyond more directly accounted for questions around usability, cost, and organizational (re)engineering.

If academic analysts are only starting to come to terms with this point, participants and stakeholders in infrastructural change have long known and acted on it, crafting practical responses to change that would-be designers (and would-be analysts) ignore at their peril. Such moves and counter-moves constitute what we might term (borrowing from Charles Tilly) the "repertoires of contention" in infrastructure: the distinctive ways and registers in which people and groups fight over, around, and through the systems and networks that govern their lives (Tilly, 2007). Like the effects of infrastructure, these range widely in scale: from the German secretary described by Pipek and Wulf who (re)constitutes herself as an integral node (or "obligatory passage point" (Latour, 1987)) in an e-government application that has otherwise passed her by, to the much-discussed (and much-misunderstood) case of the 19th century Luddites, fighting an ultimately unsuccessful rearguard action against the mechanization and globalization of the world textile industry. They also range widely in form: from the hot politics of machine breaking, institutional striving, and organized opposition, to the cool politics of studied indifference and non-adoption. Our point is not to celebrate any particular form or side in the process of infrastructural contention, but rather *merely to recognize it*, in a way that design-oriented, determinist, or narrowly functionalist approaches to infrastructure have to date almost entirely failed to do.

5. Conclusion

By the end of this issue, you will not have been presented with a clear agenda for the emergent field of infrastructure studies — though this is immanent in the papers themselves. Further, the agenda is of necessity a moving object. We are transformed by our infrastructures at all social and organizational levels. We do not have to think far back into the past to see this. The geographical dispersion of the nuclear family was impossible without the rise of railroads and later phones — the railroads and steamboats in turn being central to setting up national and international divisions of labor that enabled this social change. As Richard John has argued (John, 1995), we became different kinds of citizens once we had railroads bearing newspapers allowing us to engage in national debates in America.

So the first item on the agenda is that everything is up for grabs — what it means to be a person, a citizen, a community, an organization, and a nation. Although the consequences of the new infrastructure are profound, pervasive, and persistent, as with all previous infrastructures, true social debate has lagged safely behind some irreversible decisions — as a rule of thumb, between 20 and 40 years behind. We need to articulate academic concerns that can traverse the social and computational sciences. A perspicuous set of sites to organize around — reflected in this issue — are those where moral and social qualities are being distributed between people and infrastructure on a regular basis. For us, this means that questions of distribution, power, and justice need to be addressed urgently and systematically by our field. How can claims on, through, and against infrastructure be formulated, organized, and heard? What constitutes adequate representation or participation in the process of infrastructural change and development? Under what conditions can rival interests in infrastructure (large and small, modest and profound) be acknowledged, addressed, and accommodated, in ways that enhance the legitimacy, appropriateness, and long-term efficacy of infrastructural change?

The second, consequent item is that the "stovepipes" and "silos", so typical of the disciplines necessary to the field, need to be interwoven in a rich way. There are two rough ways of doing interdisciplinary work: mixing and matching areas somewhat at random (all too common a case), or setting up dynamic research teams to address new sets of problems. The field needs new centers — perhaps along the lines of the NSF-funded Science and Technology Centers, where interdisciplinary teams converge over a period of years to explore transdisciplinary issues — as well as new ways of conceiving the fundamental framework of education and research, such as emerging programs in social informatics that emphasize the role of information infrastructure in social life and vice versa. Only through such mechanisms can the true issues of rethinking the new social and natural sciences in response to our transdisciplinary world be brought to fruition.

Finally, as the papers in this issue make abundantly clear, there really is just one field here. If we get caught up in reified distinctions between science and business, community organizing and national politics, then we are missing precisely the harmonic development of our new infrastructure — which can be both a strong inheritor of past 'ways of seeing' and yet also frequently judiciously blind to distinctions premised on previous infrastructures.

This set of papers has given us, as editors, some excellent tools to think with. We hope that you, the reader, will also find them of value.

Acknowledgments

The special issue editors would like to thank the participants in the NSF Workshop on "History and Theory of Infrastructure: Lessons for New Scientific Cyberinfrastructures" in September 2006 (Edwards et al., 2007), and the University of Edinburgh/ESRC/e-Science Institute Workshop on "Information Infrastructures and Architectures" 27-28 September, 2006 (http://www.nesc.ac.uk/esi/events/700/). Many of those participants served as reviewers for this collection. We also thank Kalle Lyytinen and Yusun ??. Some of this work was supported by US National Science Foundation awards SES-0630263, BCS- 0827333, and BCS-0827316 and by UK Economic and Social Research Council Awards RES-335-25-0022 and RES-000-23-0466.

References

Bowker, G. C., and Star, S. L. (1999). *Sorting Things Out: Classification and its Consequences*. Cambridge, MA: MIT Press.

Edwards, P. N. (1998). Y2K: Millennial Reflections on Computers as Infrastructure. *History and Technology, 15*, 7-29.

Edwards, P. N. (2002). Infrastructure and Modernity: Scales of Force, Time, and Social Organization in the History of Sociotechnical Systems. In T. J. Misa, P. Brey and A. Feenberg (Eds.), *Modernity and Technology* (pp. 185-225). Cambridge, MA: MIT Press.

Edwards, P. N., Jackson, S. J., Bowker, G. C., and Knobel, C. P. (2007). *Understanding Infrastructure: Dynamics, Tensions, and Design*. Ann Arbor: Deep Blue.

Grübler, A. (1996). Time for a Change: On the Patterns of Diffusion of Innovation. *Daedalus, 125*(3), 19-42.

Hanseth, O., Jacucci, E., Grisot, M., and Aanestad, M. (2006). Reflexive Standardization: Side Effects and Complexity in Standard Making. *Management Information Science Quarterly, 30*, 563-581.

Hughes, T. P. (1983). *Networks of Power: Electrification in Western Society, 1880-1930*. Baltimore, MD: Johns Hopkins University Press.

Jackson, S. J., Edwards, P. N., Bowker, G. C., and Knobel, C. P. (2007). Understanding Infrastructure: History, Heuristics, and Cyberinfrastructure Policy. *First Monday, 12*(6).

John, R. R. (1995). *Spreading the news : the American postal system from Franklin to Morse*. Cambridge, Mass.: Harvard University Press.

Latour, B. (1987). *Science in Action: How to Follow Scientists and Engineers through Society*. Cambridge, MA: Harvard University Press.

Latour, B. (1996). On actor-network theory: a few clarifications. *Soziale Welt 47*, 369-381.

Latour, B. (2005). *Reassembling the social : an introduction to actor-network-theory* (Vol. Clarendon lectures in management studies). Oxford ; New York: Oxford University Press.

Law, J. (2003). Notes on the Theory of the Actor Network: Ordering, Strategy and Heterogeneity: Centre for Science Studies, Lancaster University, .

Massey, D. (1993). Power-Geometry and a Progressive Sense of Place. In J. Bird, Curtis, B., Putnam, T., Robertson, G., Tickner, L. (Ed.), *Mapping the Futures: Local Cultures, Global Change*. New York: Routledge.

Tilly, C. (2007). *Democracy*. Cambridge: Cambridge University Press.
Wagner, I. (1993). A Web of Fuzzy Problems: Confronting the Ethical Issues. *Communications of the ACM, 36*(4), 94-101.
Pollock, N. and Williams, R. (2009) *Software and Organisations: The Biography of the Enterprise-Wide System - Or how SAP Conquered the World,* London: Routledge

About the Authors

Paul N. Edwards is Associate Professor of Information at the University of Michigan School of Information. He writes about the history, politics, and culture of computers, climate science, and information infrastructure. He is the author of *The World in a Machine: Computer Models, Data Networks, and Global Atmospheric Politics* (MIT Press, in press) and *The Closed World: Computers and the Politics of Discourse in Cold War America* (MIT Press, 1996).

Geoffrey C. Bowker is Mellon Professor of Cyberscholarship at the University of Pittsburgh School of Information Sciences. He has written extensively on infrastructure, informatics, and the sciences. He is the author of *Memory Practices in the Sciences* (MIT Press, 2006) and co-author (with Susan Leigh Star) of *Sorting Things Out: Classification and Its Consequences* (MIT Press, 1999).

Steven J. Jackson is Assistant Professor of Information at the University of Michigan School of Information. He writes on the growing role of IT forms and practices in shaping contemporary systems of knowledge and governance. He is working on a book about the role of computer simulation models in shaping, aiding, and constraining water management practices and politics in the American Southwest.

Robin Williams is Director of the Institute for the Study of Science, Technology and Innovation at the University of Edinburgh. His research has examined the social shaping of a range of information and communication technologies. He is co-author (with Neil Pollock) of *Software and Organisations: The Biography of the Enterprise-Wide System - Or how SAP Conquered the World* (Routledge, 2009), and (with James Stewart and Roger Slack) of *Social Learning in Technological Innovation: Experimenting with Information and Communication Technologies* (Edward Elgar, 2005).

Journal of the Association for Information Systems

ISSN: 1536-9323