Complex city systems: Understanding how large technical systems innovation arises in cities

N. Leon

Information and communications technology (ICT) is being exploited within cities to enable them to better compete in a global knowledge-based service-led economy. In the nineteenth and twentieth centuries, cities exploited large technical systems (LTSs)—such as the telegraph, telephony, electrical networks, and other technologies—to enhance their social and economic position. This paper examines how the LTS model applies to ICT deployments, including broadband network, municipal wireless, and related services, and how cities and city planners in the twenty-first century are using or planning to use these technologies. This paper also examines their motivations and expectations, the contribution to date, and the factors affecting outcomes. The findings extend the LTS model by proposing an increased role for organizations with respect to an individual agency. The findings show how organizations form themselves into networks that interact and influence the outcome of the system at the level of the city. The extension to LTS, in the context of city infrastructure, is referred to as the complex city system framework. This proposed framework integrates the role of these stakeholder networks, as well as that of the socioeconomic, technical, and spatial factors within a city, and shows how together they shape the technical system and its socioeconomic contribution.

Introduction

International competitiveness in the twenty-first century strongly relies on the concept of innovation [1], and cities play a leading role in the fostering of innovation. Cities are becoming cauldrons of innovation that can enrich not only their surrounding regions but also their nations. More than half of the world's population is now urbanized, with existing cities growing rapidly and entire new cities being constructed to meet the needs of this growing urban population. Cities are being transformed by population growth and the need both to compete in the global knowledge-based service-led networked economy and to address local and global sustainability.

The research presented in this paper explores how cities are being transformed by the introduction of digital technologies into what firms such as IBM, Intel, Motorola, and British Telecom (BT) often refer to as smarter cities through major renewals of their information and communications technology (ICT) infrastructure, the provision of new services for businesses and individuals, and the transformation of public service delivery. This paper summarizes an extensive research program undertaken between 2007 and 2009 of 168 U.S. cities and detailed case studies of nine cities in Europe and the United States. It explains how the large technical system (LTS) theory [2, 3] helps explain the development and likely challenges in the deployment of this digital infrastructure and proposes an extension of LTS theory for cities that we refer to as the complex city system (CCS) framework. LTSs are systems or networks of very large complexity or size, and the study of such systems is a subdiscipline of the history of science and technology.

Digital Object Identifier: 10.1147/JRD.2010.2090990

This paper reviews the studies undertaken in European and U.S. cities and proposes a reinterpretation of the LTS theory [3]. The research findings highlight the importance of a specific group of stakeholders on whom the success or failure associated with the rise of a new technological system may ultimately depend. This paper proposes that these stakeholders, or organizational actors, play a much greater role in the successful development of new systems than an individual human agency associated with the LTS theory. By human *agency*, this paper refers to the actions of an individual in response to a situation rather than the actions of an organization. This paper concludes with a discussion of the CCS framework and shows how it enhances the application and effectiveness of LTSs in the emerging field of smarter cities. This paper also shows how it enables the development of new insights on LTS innovation in the context of the city.

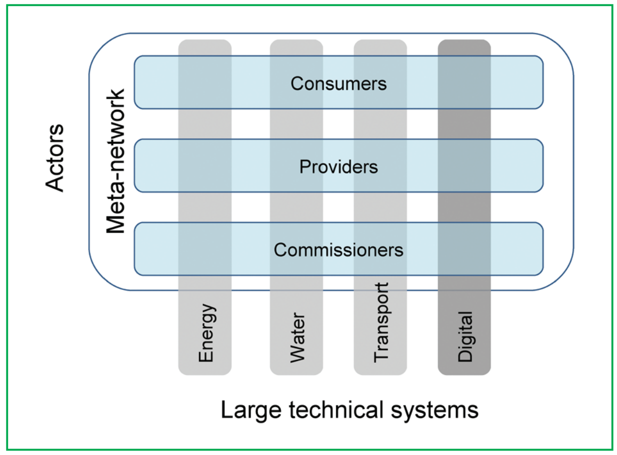

Figure 1

Matrix of LTSs and actor networks.

Relationship between distinct communities of actors and LTS

The infrastructure of a city involves several LTSs, each of immense complexity. This paper focuses on one of these systems—broadband networks—along with related digital services. This ICT infrastructure resides alongside other technical systems of a city that provide services such as energy, transport, waste, water, among others. We can consider the stakeholders, or actors, in three distinct communities:
1) the actors that *consume* the services offered by the system; 2) the actors that *provide* the system; or 3) the actors that *commission* another party to design or deploy a system. All of these groups draw upon various resource networks within or beyond the city. **Figure 1** depicts the actors and technical systems matrix, along with the intersections between each system and the consumers, providers, and those that commission the design and deployment, which this paper refers to as the commissioners. The case studies and a reinterpretation of the LTS model developed by Thomas Hughes, American historian of technology, suggest the role of a meta-network of actors that may be external to the city and may even be international. This network takes on the role of organizing the technical system and the network of providers, promoting the value of such networks to consumers, and guiding (or at least influencing) the commissioners in their system deployment and exploitation strategy. This paper addresses the roles and interplay of these actors, particularly this organizing or meta-network of actors, and their contribution to determining the successful outcomes of LTS.

Role of organizations versus individual human agency

As Thomas Hughes acknowledges, "growth [of LTSs] was not fore-ordained; it was usually promoted. Special note was taken of the process by which a new system emerged as a result of the failure to solve a major problem in the old system. At the end of this process, the old and new systems existed for a time in a relationship of dialectical tension" [2]. However, the questions that are not fully articulated in LTS work include the following: Who does the promoting, and what is the promoter's motivation? Who is taking note of the failure to solve major problems in emerging systems? Who, in turn, will solve those problems and how are problem solvers selected? Constant [4] points out that the LTS model leaves these questions unanswered. He asks how these technical, economic, or political challenges, which Hughes refers to as *reverse salients* [2], are parsed into solvable critical problems. Constant notes that while some problems can be easily resolved, the more complex problems or "recalcitrant reverse salients" need to be deconstructed and may require multiple iterations and the extensive engagement of multiple communities, organizations, and institutions. A reverse salient is an aspect of a complex sociotechnical system that either lags behind in compliance with standards or slows the advancement of a system and thereby prevents the system as a whole from developing. Davies [5] notes that by emphasizing that technical systems are socially constructed, Hughes invokes voluntarism, stressing contingent issues of action—choice, decision, and purpose—over those of structure that operate independently of individual human agency. Thus, we may ask to what extent are organizations playing a significant role in the earlier phases of development, adoption, and growth of a system, and how does this compare to the role of the individual?

The first part of this paper considers these questions and proposes an extension to LTS with an alternative view of the role of organizations and the relative importance of the

Table 1 Attributes of the case study cities and districts. The geographic attribute refers to where the digital initiative that was the focus of the case study was deployed only in the city center or across a highly distributed geographically dispersed environment. The motivation attribute reflects whether the city was motivated in terms of economic development, addressing the issues of social exclusion, or transforming the quality, productivity, and effectiveness of its public services.

City	*Geography*		*Motivation*		
	City center	*Distributed*	*Economic*	*Exclusion*	*Public service*
Barcelona	*		*	*	
Corpus Christi		*	*		*
Shoreditch	*			*	
Canary Wharf	*		*		
City of London	*		*		
Stuttgart		*	*		
Karlskrona		*	*	*	*
Norfolk		*	*		*

individual. The second part of this paper formalizes the CCS framework to examine the different actors involved and to identify the crucial role of a specific group of actors, a meta-network of actors, responsible for developing and choreographing the overall socioeconomic and technical system, and building or maintaining the momentum of that system. Technological momentum, a concept introduced by Hughes, refers to the fact that LTSs tend to continue along a path; for example, the electric power industry continues to be based on large centralized generators, although solar and other small-scale generation may be efficient and environmentally desirable.

Research method

As mentioned, the research involved detailed case studies in nine cities in Europe and the United States. The research took place at the level of the city as a whole in smaller cities; however, in larger cities, including London and Barcelona, the unit of analysis was the city district. The qualitative research was complemented by a quantitative analysis of 168 U.S. cities at the level of the Metropolitan Standard Area. This analysis indicated a link between the growth of broadband network usage and key socioeconomic indicators, including house prices, employment, high-school completions, and earnings; however, the degree of variation between cities also indicated many other contributing factors, hence the need for the detailed case studies to examine those factors [6].

The case study cities included examples in the United States and northern and southern Europe. To make access easier and reduce travelling of the researchers, the case study analysis was limited to Europe and the United States, although the literature on cities in Southeast Asia and China was reviewed. **Table 1** shows the attributes of the case study cities and districts.

Within each of the main actor groups (e.g., city authorities), the research involved a three-level approach common in organizational studies: 1) individual; 2) subunit; and 3) organization. For example, within a city, the district or borough may be the organizational unit, the infrastructure services department is the subunit (or economic development group), and the individual professional or manager is the individual. The same model was applied to private sector firms (e.g., board, chief technology officer, or deployment manager). The total number of interviews undertaken was 103. A summary of the case study cities and districts is shown in the Appendix. These include a study of the deployment of new public services, digital infrastructure, and a major urban and economic regeneration program in Barcelona; also included are studies of three contrasting boroughs in London, including Shoreditch, which was focusing on the use of digital technologies for social inclusion, and the City of London and Canary Wharf, where the emphasis of their wireless digital initiatives was on economic development. In the United States, we examine Corpus Christi and its initiatives to improve public services, specifically the utilities of the city and the use of the data network (e.g., wireless networks) to support a range of applications for emergency services, code enforcement, and services for small businesses. European case studies include cities in Germany and Sweden that sought to improve city competitiveness both nationally and internationally and, in the latter case, demonstrate a highly integrated approach to economic development, enhancements of social capital, public service transformation, and infrastructure renewal. Here, the phrase *city competiveness* refers, in part, to the ease with which value-creating activities can take place in a city and, for example, to the ability to attract skilled workers and to become desirable locations for global or regional headquarters of companies.

Extending LTS theory for cities

We begin with a brief reprise of the LTS model and an examination of the relative roles of the different stakeholders in systems technological invention, innovation, transfer, and growth. In this section, we first consider the role of the individual and then reflect on the roles of organizations in each of these phases and in the achievement of technological momentum and systems maturity. Consideration of the findings of the case studies and a reflection on the literature led us to a new understanding of a very specific set of stakeholders—a meta-network of actors that plays a pivotal role in overall systems development.

One "strand" of the LTS model is associated with the development of a technological framework that integrates successive technological components into complex systems, as explained using the example of electrical networks. The model describes the roles of individuals such as Emil Rathenau, Werner von Siemens, Charles Merz, Sebastian Ferranti, and Oskar von Miller in the transfer of these technologies internationally. The growth of these systems was characterized by specific reverse salients in the advancing technological front, and we have observed that Thomas Edison was faced with simultaneous economic, political, and technical challenges [7].

At each stage in the development of LTS, a different style of problem solver was required, and the LTS literature highlights the emergence of the inventor entrepreneur (Thomas Edison), the manager entrepreneur (Samuel Insull), and the engineer entrepreneur (Oskar von Miller). LTS theory suggests the role of the organization as being more important than individuals as systems gather momentum with the emergence of a specific technology culture with distinctive values, systematized knowledge, large-scale institutions, and the career commitments and investments of practitioners [2].

While LTS theory addresses the relationship between individuals and organizations, it is the individual that has primacy until the later stages of systems development. Hughes [2] emphasizes that at almost every stage, they are the prime actors whose individual actions and leadership propel the propagation of systems. He considers the complementary role of the organization but stresses its importance only as momentum builds and systems mature.

The view that emerges from the initial development and growth of broadband, municipal wireless networks, and related services, particularly movements such as wireless cities, involves communities of stakeholders working in organizations and competing in social networks rather than the emergence of inspired individuals. The development of these technologies and the resulting systems, along with their pioneering adoption and subsequent exploitation in hundreds of cities, appears to be rooted in firms and institutions and based on the collaborative efforts of many stakeholders rather than individual endeavors. Thus, one may ask whether this characteristic was very different a century ago. Is there an alternative view we might consider? Is there a reinterpretation of the importance of organizations, an extended group of closely related stakeholders, that complement these individuals? Organizations, and not just individuals, seem to play a crucial role at every stage in the maturity of LTSs, not just as these systems mature.

The analysis of the development of large-scale systems—and electrical, telecommunications, and, most recently, municipal broadband networks—shows that each of the components that make up the technological system has its place in a value chain. This value chain transforms technological capability into functional value, which in turn is translated into user value. At each stage, resources and investment are required, and different actors generate business value. If the value generated at any one stage is insufficient to justify the resources or investment required, then the system is unsustainable. We can observe that all of the stakeholders involved at each stage have alternatives; however, moving resources from one system, perhaps an older system, to another newer one will be undertaken only when the returns from the older system are diminishing or the promise of greater returns from the new system outweighs the risks.

Upstream and downstream networks in the system

The rise of electrical networks was dependent on an "upstream" network of collaborators, providing the infrastructure of power plants, generating equipment, distribution networks, rotary converters, and transformers, and on "downstream" networks of systems integrators, wholesalers, engineering consultants, electrical retailers, and end-user financing that promotes these systems. By *upstream*, this paper refers to the network of partners contributing technical systems components to complete the system, and by *downstream*, this paper refers to those resources involved in marketing the solution and deploying the system. Hughes describes the complex system as being made of components, the networks in which the components were organized, and the network control mechanisms; however, these are the technological elements of the system, and the upstream and downstream networks described above must also be considered as part of the system. Successful deployment was dependent on the existing service provider actor network and its effectiveness. For instance, the development of the electrical network and electrical industries in London lagged far behind than that of Berlin and Chicago because of a fragmented approach, borough by borough, which did not enable the development of the network of service and system component providers [2]. The case study cities are facing similar challenges in the implementation of their digital initiatives.

The upstream and downstream elements of a system need to be in place for the successful commercialization of the system, and each element has to be viable technically, economically, and socially, delivering appropriate returns to stakeholders. The absence of Wi-Fi** or WiMAX** (Worldwide Interoperability for Microwave Access) end-user devices and handsets for Voice over Internet Protocol and other data communications is currently impeding the exploitation of municipal wireless networks. (Wi-Fi refers to a class of wireless local area network devices based on the IEEE 802.11 standard.) The challenge of creating economically viable models for such networks in cities such as Norwich and Stuttgart limits their deployment or threatens their future. The lack of content and applications that offered end-user value in Karlskrona during the first two years of network deployment needed to be resolved before the community started to exploit the network. All of these challenges are evident in the Wi-Fi network of the City of London, when a few months after its launch in 2007, poor promotion and lack of compelling content and end-user devices led to low levels of usage and a potentially unsustainable business model over the longer term. Hence, this demonstrates that a viable system depends on each and every link in the value chain, upstream and downstream, being in place, and that the system should be technologically and commercially sound and generate returns to every stakeholder.

Formulating and constructing the upstream and downstream components of the system do not arise by happenstance. It requires expert and inspired individuals; however, it is organizations that execute, design, structure, and promote this value chain. The organizations most motivated to do this are those that have the most to gain in economic or social terms, and that have the combination of technological, financial, and social capabilities required to undertake this role. If we examine the growth of electrical networks, we can see evidence of the crucial role played by Grosvenor Lowrey (Thomas Edison's counsel) and of Drexel, Morgan, and Company and John Pierpont Morgan himself [2]. Morgan had experience in complex systems, from Western Union Telegraph (where he first met Edison) to US Rail, where he owned more than 5000 miles of railway network. Morgan was also an early investor in Bell (i.e., National Bell Telephone Company), later to become AT&T, whose first general manager was previously employed in the US Rail Mail Services. The Morgan Banking Group appointed Theodore Vail as President of AT&T, after he resigned from Bell in 1887, to secure the success and growth of the business. The successful commercialization of Edison's laboratory inventions and accompanying upstream and downstream innovations demanded the type of sophisticated management organization with which these technologically astute financiers were familiar from earlier experience with telegraphy, telephony, and railroads.

Role of a techno-financier meta-network in the adoption of LTS

For the adoption of LTS, there appears to be a need for both multidisciplinary organizations and a proactive role of the investment banks. Hughes describes the formation of holding companies that influence, or even control, the development of the upstream components in the system by taking equity positions in components and electrical equipment and appliance manufacturers. These organizations also exhibited the same influence and control of downstream components, acquiring equity and voting stock in the utilities themselves and supporting the engineering consultants who helped firms in their transformations to exploit these technologies [2].

This paper proposes that what emerges as the primary enabler of LTS is this techno-financier meta-network that incorporates the technological and financial capacity to develop the upstream and downstream components of the value chain, foster it through the insertion of finance, integrate it through management, and which is motivated by the returns [i.e., return on investment (ROI)] that can be generated, while participating in every stage in the value chain—from the development of the network operations support systems and Wi-Fi mesh networks, in the case of broadband networks, to the smart devices and applications that deliver value to individual and business consumers. This is evident in digital broadband networks of cities that have emerging coteries of large service providers, such as BT, IBM, Intel, Cisco, and Motorola. Additionally, these firms are building around themselves a constellation of smaller partners to deliver solutions for initiatives such as IBM Smarter Cities** and Smarter Planet** [8] or Smart City Forum 2009, which Intel sponsored. The meta-network shapes the technological system and is shaped by the technical system and responds to and influences the socioeconomic system. We can see evidence of this in the case studies and in recent events, including initiatives by IBM and others, and in the literature, particularly literature involving reinterpretations of complex systems and LTS work.

The hubs of today's meta-networks are large corporations, such as the ones mentioned earlier, that use business partner support programs and vendor financing models as the main tools to develop upstream and downstream elements in the value chain. For instance, large corporations support the development and operation of direct and indirect distribution channels for their products and services, including systems integrators, value-added resellers, and retailers. Their business partners may develop solutions using their technology platforms and convert their technology into value for users. Business or public sector clients incorporate their technology into larger systems that, for example, in the case of the mobile 3G network infrastructure may be designed, developed, integrated, deployed, financed, and even operated by firms such as Siemens or Ericsson. More recently, we observe this behavior in the recent IBM Smarter Cities

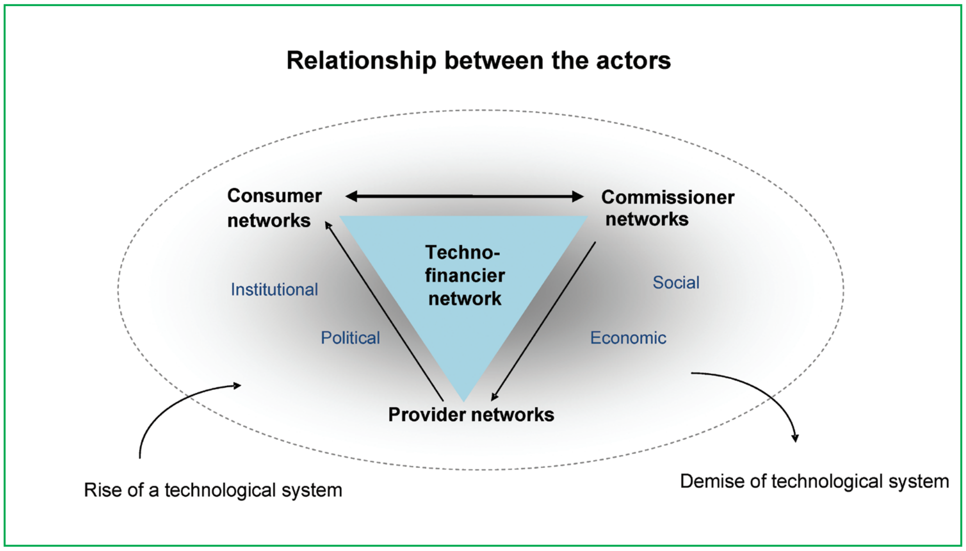

Figure 2

Rise and demise of systems in a complex and dynamic systems context proposed by Leon [6].

initiative, which is part of the Smarter Planet strategy of the company [8].

What is common to all these firms is a combined technological and financing capability and a motivation to see their technology or services integrated with the products offered by other actors in the value chain to deliver a solution for the client's needs. At the same time, these firms recognize a dependence on other parties in the network for reaping returns on their own innovations. All these firms—particularly Intel, Motorola, and Cisco—have been heavily engaged, since 2003, in promoting municipal wireless networks, as have their business partners such as Tropos and Bel-Air, who complement these vendors' technologies with carrier-grade wireless radio equipment. These smaller firms are able to provide benefit to the financing and marketing support offered by these corporations, which helps them to raise further investment from private equity firms.

In effect, firms such as IBM, Siemens, and Intel are fulfilling similar roles to Deutsche Bank, Barings, and Drexel Morgan and Company, a century earlier. Together, the firms create a techno-financier actor network, organizing and helping to develop all of the actors throughout the value chain and lobbying politically and with standards bodies to create the appropriate institutional and political conditions for the value chain to prosper and the system to become established.

The research suggests that the crucial group of actors is this techno-financier network that enables and promotes the upstream and downstream elements in the supply chain, influences the regulatory environment and market demand, and organizes and even makes the overall system operational through the coordination and development of resource networks.

Figure 2 shows four actor networks that are involved in the rise and demise of technological systems. One such actor is the *provider network* of the firms that develop and deploy the technologies and services, the telecommunications operators, the power utilities, the home appliance or industrial equipment providers, the handset or terminal vendors, the software and applications services vendors, as well as the resource networks they exploit to provide the necessary physical or skill resources.

Another actor network, shown at the left of Figure 2, is the *consumer network*, which includes both individuals and business consumers. An example of a highly influential business consumer network is the network of large corporate users and electronics manufacturers that lobbied governments in the 1960s and 1970s to dismantle the closed and monopolistic telecommunications markets [5]. In the case studies, the *commissioner network* comprises the city authorities, municipalities, related agencies, and communities seeking to deploy broadband networks and deliver new or improved services to consumers. The *techno-financier network*, illustrated at the center of the triangle in Figure 2, coordinates and fosters the triangular relationship between the others.

The system is completed by the social, economic, institutional, and political environment in which these actor networks are embedded, as shown in Figure 2. The rise or demise of a technological system depends on its acceptance by these networks and the value each of these networks derives from the system. It is the techno-financier network that identifies and characterizes the reverse salients and determines which resources in the service provider network are most appropriate to resolve them. This network attempts to direct the system, identifying gaps in the value chains or networks that might inhibit the development of the system, and promotes the value of the new services for consumers while influencing the commissioners in terms of how they can deliver more value to the clients or communities they serve.

To summarize this section, well-integrated multidisciplinary organizations rather than individuals are playing the more important role in LTS invention, integration, design, and commercialization. Additionally, all the components in the value chain of the system need to be in place to transform technological capability into user value, and each of these components needs to be technologically and commercially viable to generate ROIs for the relevant actors in the value chain; otherwise, the chain is not viable and the growth of the system falters or fails. Finally, the overall organization and animation (i.e., energizing) of the value chain of the system rely on a techno-financier network, which identifies gaps in the organization and weaknesses in the component parts of the value chain and determines which elements need to be resolved and by whom, thereby resolving the gap in LTS theory highlighted by Constant [4] and Davies [5] in the introduction to this paper.

CCSs and LTS

In framing the case study analysis, we develop an initial conceptual framework, i.e., the CCS framework. This incorporates Hughes's seminal work on complex systems [2] and LTS theory [9] viewed from the perspective of the city. It is an integrated framework that builds on prior work in the technical systems domain and incorporates components of the city environment, including such dimensions as social and economic dimensions as well as dimensions related to physical and spatial organization, urban planning, public service delivery, and governance [6]. This framework also accounts for the different stakeholders involved in the supply and deployment of the elements of the technical system, the consumer networks, and the commissioning and managing networks, typically the city authorities and related agencies. This is illustrated in **Figure 3**, which shows the CCS conceptual framework.

The CCS framework establishes an urban context for the analysis of LTS. It addresses the complex social, political, and economic system that Hughes refers to as a *seamless web* and provides a framework to consider each system component as well as its relationship and connection to other components.

During the case study research, city officials and service providers stressed the importance of a number of other factors, including the need to transform public services, spatial planning in regeneration districts, economic development strategy, programs for developing social capital, and governance. As a result of this input, the interview questions were reformulated, and earlier findings and case descriptions, along with the case studies, were revisited. As a result, the LTS framework was extended into the CCS framework, adding the components listed in **Table 2**, and refined these components of CCS during the research program as a result of a systematic analysis of the case study input. This also required a revisiting of the initial literature and extensions to the literature review to incorporate additional features related to urbanism [10, 11], capabilities, and the adoption and diffusion of innovation. A more comprehensive explanation of the CCS framework is available in the author's Ph.D. thesis [6].

Components of the CCS conceptual framework

The purpose of the CCS conceptual framework is to better integrate the multiple system components involved in the deployment of LTS, including social capital (defined in the next section), the economic development strategy, spatial organization and planning, the technological systems infrastructure and the services and content it delivers, and the principal actors involved in the commissioning, provisioning, deployment, and consumption of services. This approach provides a flexible and inclusive framework for the analysis of the sociocultural context for the invention, development, and evolution of LTS in a city context, and provides a conceptual framework to address the gaps in the LTS model identified earlier.

Relationship between the components of CCS

The initial round of interviews in the case study cities, a review of the available literature, and participation in policy and practitioner conferences showed that the sociocultural context referred to in the LTS model is highly influential in shaping the deployment of technological infrastructure in a city. In the proposed CCS framework, the nature of the technological infrastructure is influenced by the spatial organization of the city and the strategic planning for urban development. This, in turn, is influenced by the physical environment of the city and its relationship to other regional, national, and international conurbations, as described by Hughes [2]. Values are provided by the exploitation of the infrastructure in terms of the software applications available to organizations and institutions and by the services provided by the public and private sectors to these communities. The governance of the city authority, its agencies, or private sector partners (which include the prioritization, development, and deployment strategy of these applications and services as well as the enabling infrastructure) may influence the scope and effectiveness of these applications and services. Similarly, the extent of their alignment with the economic development strategy for the city is likely to have an impact on the value that is derived from the technological infrastructure and its exploitation. One of the pillars of CCS is *social capital* and *human capital*,

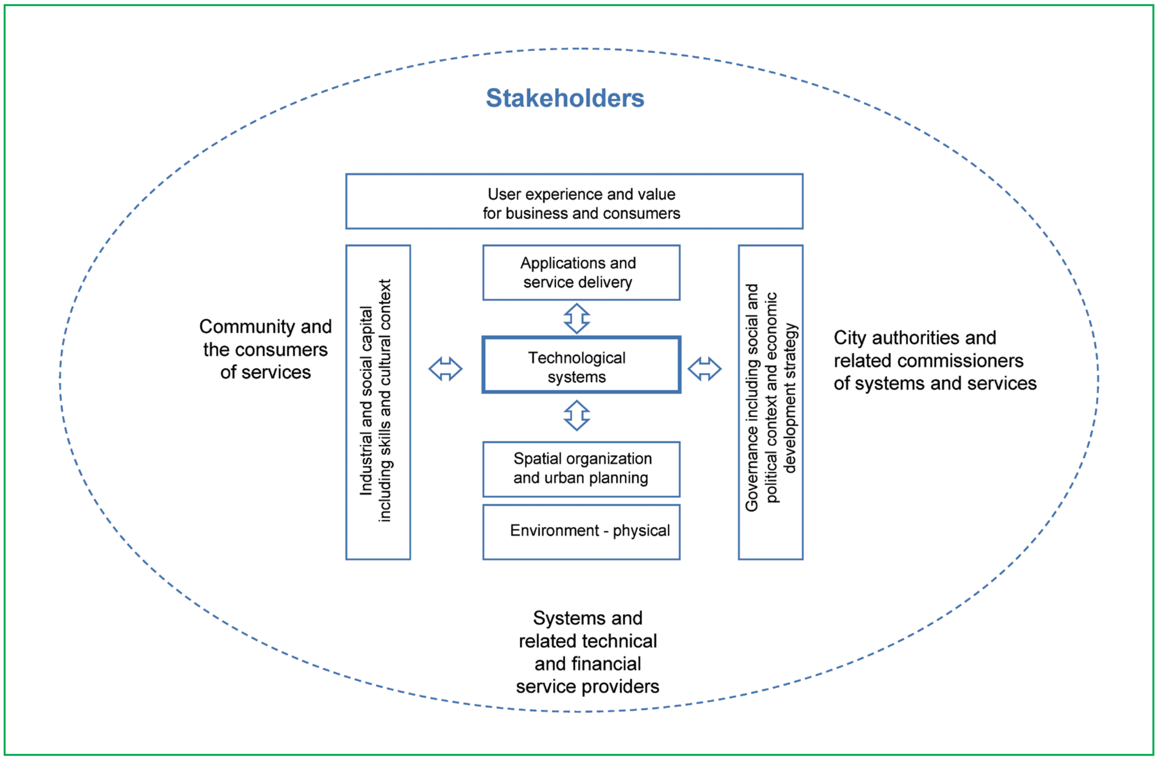

Figure 3

CCS conceptual framework. The four double arrows represent the "forces" and features that interact with and influence the nature of the technological system. The term spatial organization is discussed in the section "Components of the CCS conceptual framework."

terms that refer to the skills and talents of its citizens and the vitality of their social networks. In the case study of Barcelona, we note that the propensity to both attract and connect the international community of the city is a crucial component in enhancing the social capital of a city [12]. Social capital not only has an impact on the nature and exploitation of the services provided, but it is a crucial element in realizing the city's goal of transformation for a knowledge-intensive economy. Table 2 summarizes the key components of CCS and the specific factors that need to be considered within each component. Table 2 also lists various spatial characteristics of the city, for instance, whether the city is a highly concentrated city or whether it is *polycentric* in nature with multiple urban concentrations linked one to another [10, 11]. We consider the industrial and social capital, including the degree to which international firms are embedded in the region, relying on a network of suppliers, or skilled resources that inhibit their willingness to relocate [13, 14], as well as the *sectoral characteristics*, which refer to the industry sectors present in the city or region and the economic conditions pertaining to those sectors. We explore the governance component (Table 2) in more detail later in this section.

Relationship between the different networks of actors in CCS

The case studies highlighted the role of governance as being the most important component of the CCS model. This component addresses the relationship between the different networks of actors, including the commissioners, providers, consumers, and the organizing (or meta-network) actors. The governance model is the component that manages the relationships between these networks; for instance, the component ensures that the services delivered to consumers are the most appropriate and have the best value for business and households. It also ensures that the financial model provides returns that motivate all of the actors involved in the provision of services, including the upstream and downstream networks. Finally, it ensures that the design of the infrastructure and services is aligned with the commissioning city or agency's economic and social goals.

This component of CCS involves integration of the technological system with the city or district economic development strategy and related programs. It has a series of subcomponents that include the following features and strategies.

Table 2 Conceptual framework showing the key factors influencing each component. Many of the terms used in this table are discussed in the section "Components of the CCS conceptual framework."

Component of CCS	*Factors*
Governance	Economic development strategy and programs
	Competencies and capabilities
	Accessibility of programs and agencies
	Public and private partnership
	Trust and transparency
Industry and social capital	Education and skills and competency building
	Engagement of universities and industry
	Social cohesion and inclusion
	Vitality of social networks
	Sectoral characteristics
	Entrepreneurship and innovative capacity
	Embeddedness of industry
	Intra-regional and international linkages
Spatial organization	Centricity and polycentricity
	Industry clustering
	Proximity of work and residents
	Accessibility and transport
	Formal and informal spaces for innovation
Environment	City and district amenities
	Relationship to other urban and industrial center
	International accessibility
Applications and service delivery	Infrastructure services
	Social and community services
	Business services
Actor networks	Business and individual consumer networks
	Provider networks
	Commissioning networks
	Organizing or meta-actor networks

Economic development strategy

The economic development strategy factor includes the support for new ventures, the provision of incubation facilities, and the related business and infrastructure services that are enabled by the technical system. The Karlskrona case study shows how the deployment of its broadband network and related services was carefully integrated within the overall policy to transform the city from shipbuilding and a major naval base to becoming Sweden's "Telecom City" (see the Appendix). Similarly, in Barcelona, Ramon Sagarra, who is responsible for the infrastructure of Barcelona, designed the network and its capacity and accessibility in accordance with the city strategy to transform the aging industrial districts of Poble Nou and St. Marti into the 22@Barcelona innovation district (see the Appendix) and to support the various industry clusters with appropriate network capacity and other new technical systems, including power, waste, and water systems [12]. In other cities including Norwich, this degree of strategy integration is not evident, and interviews with users highlighted issues related to availability, capacity, and cost and reliability of the digital network.

Competence and capabilities

The competence, capabilities, and capacity of the city authorities who are commissioning technical systems varied widely in the case study cities. The capabilities of the City of London and Canary Wharf (see the Appendix) were markedly different from those of Barcelona; the London boroughs both commissioned partners to design, deploy, and operate their systems and adopted an open-systems approach to the provision of additional applications and services. In contrast, Barcelona developed an extensive infrastructure and large-scale project management and technical capabilities using the city's own resources rather than outsourcing to specialists. It was able to not only design the system on its own but also develop a rich suite of applications to exploit the system. Barcelona is unusual in its capacity to assume the role of systems integrator. There are strong similarities between the approach of Barcelona and the deployment of electrical networks in Berlin in the nineteenth century. The Berlin city authorities were able to work effectively and closely with Siemens and Allgemeine Elektrizitäts-Gesellschaft (AEG) and deploy many new and innovative services for the industry, the consumer, and the transportation services that included electric trams. These services were based on the capabilities of the city and the technical and operational ability to partner with innovative firms, such as Siemens and AEG.

Awareness and accessibility of city programs

One of the challenges that emerged from the case studies was the need to ensure awareness and accessibility of the business and support programs offered by the city and its agencies. While in many ways the programs in Barcelona are exemplars, business owners commented on the lack of awareness or confusion and overlaps between the agencies providing services and the conflicting information provided by different agencies. These services included digital-network services and business portals and incubators for new business, all of which were enabled through digital broadband networks, wireless, or related services.

Public/private partnership

The relationship between public and private sectors has at least two aspects relevant to CCS. The first relates to the model exploited by the city to partner with a service provider; for instance, the public sector agencies in Norfolk, Stuttgart, and Corpus Christi made the initial investments themselves and initially owned all the assets and managed the operation of their networks. Stuttgart and Corpus Christi subsequently transferred the assets and outsourced operations to private sector partners. The City of London chose, from the outset, to partner with a service provider. The form of partnership influences the physical nature of the technical system, which in this case involved the broadband and wireless network, including its geographic coverage, the openness of the system, and its capacity to support new applications regardless of the source of innovation.

Another aspect is the connection between local industry, universities, and government agencies within the city and their combined engagement in shaping overall objectives, requirements, and exploitation of the technical system. The nature of this public–private partnership influences the overall design and the ultimate value delivered by the system.

Trust and transparency

Trust and transparency involve the willingness of the private sector to invest and its confidence in being able to secure long-term returns. This was a challenge in the nineteenth century, particularly in London, when the emerging electrical utilities were not confident that they could ensure long-term returns under the initial Electricity Supply Acts, and it is evident at the start of the twenty-first century in London where each borough is working independently and on relatively small-scale projects with different service providers. Trust and transparency also relate to the firms' exploitation of the new technical systems. The Norfolk case study demonstrated the unwillingness of firms to exploit the new network unless they are sure of its sustainability in the long term and sure of extensions to its coverage. Decisions by the city authority should be evident, or transparent, and not made by a closed group that would reduce trust.

Advantages of using the CCS framework

CCS provides a framework that integrates several features and areas, including 1) governance, considering the importance of the different stakeholders involved in the design, deployment, and management of LTS infrastructure; 2) the status and development of social and human capital; 3) the economic development strategy at the level of the city region; 4) the city or district spatial organization and urban planning; and 5) the collective impact of these areas on shaping the technical systems infrastructure and the services and content that the system delivers.

CCS enables a more complete understanding of the social, political, and economic context for the invention, development, and subsequent evolution of LTS in a city context. It integrates LTS with the innovation, urban systems, and capabilities literature and helps to resolve the gaps identified in LTS theory described in the Introduction. The sociocultural context referred to within LTS is very specific in terms of the deployment of infrastructure within cities. If an LTS, such as a digital broadband and municipal wireless network, is to play an important role in the transformation of a city to a knowledge-intensive economy and is to help it become a hub of innovation, then a much more integrated approach is required. It is crucially important, as the case studies show, to understand how the sociocultural and economic components of the city shape the requirements for the technical system and are an integral part of the total systems strategy. CCS offers a better understanding of the roles and interactions of the different actor networks, particularly the techno-financier network for the development and future evolution of a specific LTS.

The CCS framework also helps explain how the nature of the technological infrastructure is influenced by the spatial organization of the city and the strategic planning for urban development [10, 11]. This, in turn, is influenced by the physical environment of the city and its relationship to other regional, national, and international conurbations. Value is derived by organizations and users at the point at which new applications, content, or services are delivered to them by the public and private sectors. The governance of the city authority, its agencies, or private sector partners—including the prioritization, development, and deployment strategy of these applications and services, as well as their enabling infrastructure—influences the scope and effectiveness of these applications and services. CCS helps cities and city planners to consider the impact of different ownership and partnership models and the importance of these for ensuring sustainability. Similarly, the degree of alignment with the economic development strategy of a city has an impact on the value the city derives from the LTS and shapes the nature of its use and extent of its exploitation. A pillar of the CCS is social and human capital (the skills and talents of its citizens) and, as mentioned in the case of Barcelona, the propensity to attract and connect the international community that resides in the city to enhance the social capital of the city. This component has an impact on the nature and exploitation of the services provided and is a crucial element for the city to achieve its goal of transforming to a knowledge-intensive economy.

Summary and conclusion

The CCS framework provides a more complete model than LTS theory for application to cities. It addresses the way that the different actors and their networks combine and interact and relate to the key socioeconomic, cultural, and spatial factors at work within the city. This combination of factors and actors shapes the technological system and influences its ultimate contribution. The techno-financier meta-network is not addressed adequately by the LTS model. Without the techno-financier meta-network in place, new technological systems, such as digital broadband initiatives and specifically municipal Wi-Fi-based wireless networks, are less likely to succeed. Cities and districts introducing these new initiatives need to have the internal capabilities and competencies to engage effectively with powerful service providers (e.g., services providers that are large firms). A technical systems strategy led by a service provider that is not aligned with urban planning and social and economic development strategies is less likely to be successful. It is important to recognize the uniqueness of the social, cultural, and spatial context. The CCS framework can help cities and city planners to understand the different components of these strategies, manage the interactions between the different networks of actors, and plan their integration to achieve successful outcomes.

The role of such a techno-financier meta-network is not new but emerges in reinterpreting the deployment of LTS in the nineteenth century using the perspective of CCS. When examining the domain of ICT, one sees firms such as IBM, BT, Cisco, and Intel are fulfilling roles similar to those played by Deutsche Bank, Barings, and Drexel Morgan and Company in the nineteenth century during the rise of electrical networks. As mentioned, the techno-financier meta-network is required to organize and coordinate the value chain, and lobby politicians and standard bodies to create the appropriate political and institutional conditions to enable the value chain to prosper and to ensure that the functionality of the technical system is translated into value for businesses and individuals as part of a CCS. The research suggests that this network was as influential in the growth of telephone, telegraph, and electricity networks as it is in the development of digital initiatives in cities, and such a network will need to emerge if Smarter City initiatives of the firms mentioned earlier and the aspirations of city authorities are to be realized.

Appendix I: Summary of selected case studies

Barcelona

The city authority is seeking to create a new form of city for the knowledge economy; a city that is highly inclusive socially and culturally. There is a comprehensive renewal of infrastructure currently underway, beginning in the late 1990s. This involves redeveloping almost 200 ha of the older industrial sector of the city. The city authorities pride themselves on using enormous care to preserve the cultural heritage of the districts, to bridge the digital divide particularly with the older inhabitants of the district, and create new opportunities and skills among the young people. This redevelopment, which is known as 22@Barcelona innovation district, will be the hub of the transformation of the city to the knowledge economy. It incorporates four industry clusters that combine universities, technology transfer offices, incubators for new ventures, solution laboratories, residential housing, and offices with spatial planning and a technological systems infrastructure appropriate for the industry sector it supports. The research showed that Barcelona was unusual in having a completely integrated planning approach that incorporated its economic development strategy, social capital development, and infrastructure transformation with its urban and spatial planning.

City of London and Canary Wharf

London is a global hub for the financial services industry. To attract and retain international firms, it is imperative that London offers the finest amenities, those that help improve the operational effectiveness of the business community. Thus, deploying an "umbrella" of wireless Internet access is seen by the city authorities as enabling a highly mobile business community to have rapid and pervasive access to the latest information in a sector where every second is important. The case study explored governance, including the relationship between the actors, the issues associated with spatial integration, the nature of the applications and services exploited by users, and the role of this technology in attracting new firms and retaining the competitiveness of the City of London and Canary Wharf as global hubs for financial services firms.

Corpus Christi, Texas

The economy of Corpus Christ had been based on the presence of the navy, the port, and the naval shipyard. However, the economic development strategy of the city was based on attracting as well as developing new business, particularly dynamic, small, and medium-size enterprises (SMEs). The approach was proving successful as the city was rated forth in the United States in terms of new investment despite being the sixty-third largest city in the 2003 census. The geographic challenges are the very reverse of the City of London, as Corpus Christi covers more than 100 km^2. The city was intent on transforming the quality, efficiency, and effectiveness of its public services, which include the utilities. Exploiting one particular application, i.e., automated meter reading, which was immediately useful in terms of network deployment, the city then exploited the wireless broadband network for the provision of other applications and services to support its citizens, including pervasive broadband network, and then extended this capability to create a rich suite of services for SMEs.

Karlskrona

Rather like Corpus Christi, but at a very different scale and density, we find the town of Karlskrona, Sweden, using ICT as an enabler of policies that link economic development, enhancing social capital, transforming public services, and even making the city a "living laboratory" for new technologies and involving an actor network that brings together public and private sector, industry, and academia, and the community composed of a wide range of age groups. One of the key actors we observe in this case study is Affarsverken, the utility company for the city of Karlskrona. Working closely with the city authorities, the university, and representatives of the community and local industry, it created a strategy to turn Karlskrona into Telecom City. Telecom City includes a network of information technology (IT) and telecommunications companies present in Karlskrona that have generated a significant number of IT jobs. This is perhaps one of the best examples of an industry and economic development strategy being integrated with an infrastructure strategy. New industries have been created in a city that was previously concerned with heavy industry and had a strategic naval base for Sweden.

Norfolk county council

Norfolk launched its Open Link project in 2006 for a pilot study of wireless broadband networks for the city of Norwich and for the surrounding rural areas and villages of South Norfolk. For the United Kingdom, it was one of the largest deployments in terms of both geographic area and number of hotspots (access locations). The motivation was primarily economic development, making Norwich, in particular, a more attractive place in which to live and work, and to ultimately learn more about how these technologies could support the transformation of public services. By the end of 2007, a decision needed to be reached as to the future of the network, and this case study was developed to help ascertain the value that the network was providing to its citizens, and the perceptions of local business, and recommend in what form it might be developed further. This case study addressed the issues of governance, including the business model, the challenges of spatial integration with a highly nuclear city but a sparsely populated immediate city region, and the value that business and citizens derive from the services offered.

Stuttgart

The Stuttgart Regional Economic Development Corporation observed how important mobility was for local firms in terms of both physical transportation and information access for the community. The corporation extended the use of a network, deployed initially as part of an intelligent transportation system, and created a free wireless Internet service with a rich information portal for the community across the region. The goal was to help the Stuttgart city region differentiate itself from other regions in Germany as a place to live and work, enhance the economic development of the city, and provide a rich suite of services to both visitors to the city as well its residents. Stuttgart was also chosen because it is one of the first cities in Europe to deploy a wireless network across such an extensive area, starting in 2004, and is one of the European Union's Living Lab cities. *Living Labs* refers to a nonprofit association based in Copenhagen (Denmark) with the objective of promoting innovation in services and mobility in cities. The case study also illustrated the challenge of building user momentum (i.e., increasing adoption rates) and delivering compelling content to provide value to the users and sustained usage of the network.

References

1. US Council on Competitiveness, "Innovation: The New Reality for National Prosperity," in *21st Century Innovation Working Group Final Report,"* 2004. [Online]. Available: http://www.wired-nation.net/files/21st-century-innovation-initiative-an-nii-working-group-report.pdf
2. T. P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930*. Baltimore, MD: Johns Hopkins Univ. Press, 1983.

3. W. E. Bijker, T. P. Hughes, and T. Pinch, *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Cambridge, MA: MIT Press, 1989.
4. E. Constant, "The social locus of technology practice, community, systems or organisation," in *The Social Construction of Technological Systems*, W. E. Bijker, T. P. Hughes, and T. Pinch, Eds. Cambridge, MA: MIT Press, 1987, pp. 223–242.
5. A. Davies, "Innovation in large technical systems: The case of telecommunications," *Ind. Corporate Change*, vol. 5, no. 4, pp. 1143–1180, Jan. 1996.
6. N. Leon, "Complex city systems," Ph.D. dissertation, Univ. London, London, U.K., 2010.
7. M. Callon, "Society in the making: The study of technology as a tool for sociological analysis," in *The Social Construction of Technological Systems*, W. E. Bijker, T. P. Hughes, and T. Pinch, Eds. Cambridge, MA: MIT Press, 1987, pp. 85–103.
8. IBM, How Smart is Your City? Helping Cities Measure Progress, Somers, NY: IBM Inst. Bus. Value, IBM Press" 2009. [Online]. Available: ftp://public.dhe.ibm.com/common/ssi/pm/xb/n/gbe03248usen/GBE03248USEN.PDF
9. J. Law, "Technology, closure and heterogeneous engineering: The case of the Portuguese expansion," in *The Social Construction of Technological Systems*, W. E. Bijker, T. P. Hughes, and T. Pinch, Eds. Cambridge, MA: MIT Press, 1987, pp. 111–134.
10. P. Hall, *Cities in Civilization*. New York: Pantheon Books, 1998.
11. P. Hall and K. Pain, *The Polycentric Metropolis: Learning From Mega-City Regions in Europe*. London, U.K.: Earthscan Publications, 2006.
12. N. Leon. (2008, Oct.–Dec.). Attract and connect: The 22@Barcelona innovation district and the internationalization of Barcelona business. *Innovation: Manage., Policy Pract.* [Online]. *10(2/3)*, pp. 235–246. Available: http://www.innovation-enterprise.com/archives/vol/10/issue/2-3/article/2626/attract-and-connect-the-22@barcelona-innovation
13. E. L. Glaeser, "The rise of the skilled city," *Wharton Papers Urban Affairs*, vol. 5, pp. 47–105, 2004.
14. E. L. Glaeser, "Information technology and the future of cities," *J. Urban Econ.*, vol. 43, no. 1, pp. 136–156, Jan. 1998.

Received April 21, 2010; accepted for publication May 23, 2010

Nicholas Leon *Design London at the Royal College of Art and Imperial College London, South Kensington Campus, London SW7 2AZ, U.K. (nleon@imperial.ac.uk)*. Dr. Leon holds a B.S. degree in mechanical engineering from Imperial College London, a Master of Design RCA degree in industrial design from the Royal College of Art (RCA), and a Ph.D. degree from London University. He is Director of Design London at the RCA and Imperial College. His research focuses on the social and economic impact of information and communications technology in an urban context and on how cities are transforming their infrastructure and amenities to support the knowledge economy. He joined Design London in 2007. Prior to this, he was Director of Business Development for IBM Global Services, EMEA (Europe, the Middle East, and Africa), and was responsible for developing IBM business in the telecommunications sector. He is a Visiting Fellow of Imperial College, a Fellow of the RCA, and a Fellow of the Royal Society of Arts.