A SPATIAL ANALYSIS OF INTERNET ACCESSIBILITY

DISSEhATION

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The Degree Doctor of Philosophy in the
Graduate School of The Ohio State University

By

Tony H. Grubesic

The Ohio State University
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Dissertation Committee:
Professor Morton E. O'Kelly, Adviser
Professor Mei-Po Kwan
Professor Alan T. Murray
Professor Steven I. Gordon

Approved by

____________________
Adviser
Department of Geography
ABSTRACT

Throughout the United States, a small percentage of residents have access to the best information technology that society has to offer. Utilizing the most powerful computers, the best and most reliable telephone service, and the fastest Internet connections, these people are connected to the newly emerging digital world and capable of accessing the information economy. Other groups of people have no computers, rely on substandard telephone service, and have never used the Internet. The difference between these two groups of people is referred to as the “digital divide”. To date, efforts attempting to explore the digital divide have focused on its the socioeconomic and demographic characteristics, documenting the differences in computer use and Internet availability between different ages, races, and income groups. These research efforts do not adequately address the spatial nature of the digital divide, specifically the telecommunication infrastructure that enables Internet access.

In the increasingly competitive telecommunications industry, profit-seeking firms continue to upgrade infrastructure in select market areas creating an uneven spatial distribution of access opportunities. Utilizing a longitudinal database of Internet infrastructure, highlighting both fiber optic backbone points of presence (POP) established by commercial Internet service providers and the backbones themselves, an analysis examining city accessibility to the commercial Internet is performed. Results indicate that many larger metropolitan areas maintain dominant shares of telecom infrastructure, but several mid-sized metropolitan areas are emerging as important centers for telecommunication interconnection. In conjunction with the empirical analysis, a standardized methodology for evaluating network connectivity is outlined.
Although telecommunication infrastructure is a key component to evaluating the spatial manifestations of the digital divide, Internet activity, defined by the presence of businesses or organizations utilizing information technology, is also an important dimension. By utilizing a comprehensive database of domain registrations, basic analytical techniques, and a geographic information system (GIS), the spatial characteristics of Internet related activity are explored for the State of Ohio, at both the local and regional levels. Results indicate significant incongruities in the locations of activities associated with the Internet. In addition to the considerable differences between urban and rural locales, empirical evidence suggests transportation infrastructure and educational institutions also play significant roles in the level of Internet related activity for a region.

The final components of this thesis explore residential broadband technologies and access options throughout the state of Ohio, with portions of the analysis focusing on the economic impacts of broadband infrastructure. At the regional level, the relative lack of broadband access options in rural SE Ohio (Appalachia) is documented. An explanatory framework identifying key market characteristics indicative of demand for residential broadband services throughout the state of Ohio is also presented, with results suggesting that population density, high income and high education levels are excellent indicators of demand. The second component of the broadband analysis examines the impact of local geography on broadband, digital subscriber line (xDSL) network access. Utilizing an integer programming model, the maximal covering location problem, and a geographic information system, xDSL broadband access is evaluated in Columbus, Ohio. Results indicate that many suburban areas can be left without adequate service.
To Nellie
whose love and support
make anything possible
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Portions of this research are accepted for publication or submitted in the following journals.

Chapter 3, ‘Using points of presence to measure Internet accessibility’ is an expanded version of a paper to appear in *The Professional Geographer*, coauthored with Morton O’Kelly. Chapter 4, ‘Backbone topology, access, and the commercial Internet’ is an expanded version of a paper submitted to *Environment and Planning B*, coauthored with Morton O’Kelly. Chapter 5, ‘Regional Internet presence and activity in Ohio’ is an expanded version of a paper submitted to *Telecommunications Policy*. Finally, Chapter 7, ‘Constructing the divide: spatial disparities in broadband access’ will appear in *Papers in Regional Science*, coauthored with Alan Murray.

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VITA

1994       B.A.  Political Science, Willamette University
1996       B.S.  Geography, University of Wisconsin-Whitewater
1998       M.A.  Geography, University of Akron

PUBLICATIONS

Research Publications


FIELDS OF STUDY

Major Field: Geography
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“Human interactions occur across a system of interconnected places, extending from the busiest point in the largest of cities to the furthest spot in the most desolate of boondocks. Technological change ramifies through societies, altering economies and thereby diffusing the interactions in space. What once had to happen in the city can now take place anywhere”

(Pascal, 1987; 597-603)

The Internet is a decentralized matrix of computers, routers, and human users connected by a web of fiber optic and copper cables. With multiple formats available, the Internet also offers a variety of tools to exchange information: from email and telnet to the more complex audio and visual segment of the Internet known as the WWW. Over the past decade (1990 – 2000) the Internet has become one of the major catalysts for human interaction. Indeed, as both Hall (1998) and Malecki (2001) suggest, the Internet is the most significant technology of the intermillenial era. Classified as a general-purpose technology (GPT), the Internet and its complementary innovations have dramatic impacts on productivity across a wide variety of sectors (Breshnahan and Trajtenberg, 1995). Historically, other GPTs such as writing, printing, and electricity have had similar impacts (Lipsey, Bekar and Carlaw, 1998).

By all accounts, Internet use is growing at a staggering rate. For example, in 1993 it was estimated that the number of Internet users would grow to more than 100 million within ten years (Cerf, 1993). By 1995, the online community within the United States alone reached 56 million (OTA, 1995), and as of April 2001, the online community in the United States reached 163.4 million users (Nielson Net-Ratings, 2001). There are other measures of growth as well. For example, the number of Internet hosts available (computers reachable through the Domain Name System) and their increase over the past decade is an informative alternative. In January of
1989, there were approximately 80,000 Internet hosts. As of January 1, 2001, 109,574,429 Internet hosts were present (Network Wizards, 2001).

As telecommunication technologies continue to improve, they will also diffuse to a growing segment of home users, businesses, educational institutions, and society at large. Graham and Marvin (1996, 3) note that this type of technological convergence not only provides a foundation from which these telecommunication innovations can evolve, but their evolution will include development at all geographic scales, “from a single building to transglobal networks”.

1.1 Urban Dissolution and the Death of Distance

As the costs of both computing and information technologies continue to decrease, there exists an emerging debate regarding the spatial implications of such technologies on urban form and structure. Much of this debate centers on the economic ramifications of the Internet on urban business districts. Proponents of the ‘urban dissolution’ framework suggest that the effects of distance will be sidelined by telecommunication technology (Gillespie and Williams, 1988; Brunn and Leinbach, 1991). In essence, the constraints of geographic space and the traditional costs associated with interaction in such space will be rendered virtually meaningless by instantaneous communication, near frictionless markets, and decreased innovation time (Cairncross 1997).

“When the time taken to communicate over 10,000 miles is indistinguishable from the time taken to communicate over 1 mile, then time-space convergence has taken place at a fairly profound scale.”

(Gillespie and Williams, 1988; 1317)

Although space and distance remain salient today, there are numerous empirical examples where time-space convergence has taken place. For instance, a software firm located in Jerusalem produces products for the Japanese corporate market. Although there are occasional face-to-face meetings between the market and the producer, the vast majority of contacts are made via telecommunication (Saloman and Tsairi, 1995). Other examples can be found in the banking industry. The first fully functional Internet bank was Security First Network Bank, which opened for business in the United States in October of 1995. In the UK, First Direct
is generally considered one of the more successful telephone banking operations in existence (Richardson, 1994). Unlike traditional brick-and-mortar banks, First Direct has no physical service outlets or locations; the company operates from a 24-hour call center located in Leeds. Because of this business model, customers either complete transactions by telephone or the Internet (Graham and Marvin, 1996; First Direct, 1999).

When the preceding two examples are considered, it is clear that the effects of distance can be reduced through telecommunication technology. However, many authors argue that distance and place, now more than ever, play a pivotal role in the information economy; suggesting that as society becomes increasingly dependent on telematics, telecommunication, and the Internet, a new urban hierarchy will emerge.

1.2 The New Order

In the past, urban places (cities) were largely viewed as special nodes within a larger geographical space. Within and around these fixed nodes were a series of relations and processes that shaped the city and its environment (Massey, 1992). In part, these relationships and processes helped explain how cities grew physically, economically, politically, and socially. From a geographical perspective, distance was one of the primary influences on “place” and its characteristics. Graham and Marvin note (1996, 57), “(t)he frictional effects of distance: traveling across the Euclidean plain was expensive in both money and time so larger distances discouraged interaction”. Due to this friction, economic entities located in places that minimized the costs associated with physical access to raw materials, production facilities, and the market for their products.

Not surprisingly, many urban areas greatly benefited from their surrounding geography. A good example of this locational advantage can be illustrated by the city of Chicago and its proximity to Lake Michigan. First, the steel industry was able to receive large shipments of iron ore from Minnesota and other states located along the Great Lakes by freighter. In addition, Chicago’s role as a gateway for rail transportation allowed for easy shipment of both raw
materials and finished products to other markets (Taaffe et al., 1996). Because of these locational/economic advantages, Chicago quickly became one of the most important and influential cities in the United States.

Just as proximity to rail, water, interstate highways, and airports were important to the economic vitality of the 19th and 20th century city in the United States, the 21st Century city will place increasing importance on the availability of telecommunication networks and overall proximity to the fiber optic backbones which route and deliver information. In essence, this new urban hierarchy will be determined by how quickly a city can access and distribute information. As Mulgan (1991, 3) notes;

“The nineteenth century’s physical infrastructures of railways, canals, and roads are now overshadowed by the networks of computers, cables, and radio links that govern where things go, how they are paid for, and who has access to what.”

1.3 Purpose

There is no doubt that the Internet is making profound economic, political, and cultural changes to our world. However, before jumping to any conclusions, one must consider how far-reaching these changes will be. As stated previously, although the Internet is a massively popular way to communicate and exchange information, it is far from a global medium in its current state. In fact, the Internet household penetration rate in the most wired country in the world (United States) is less than 55%. So, although the Internet is changing the way some people live, it is far from changing the way all people live. On a global level, disparate access rates are not difficult to imagine. Many of the most rural and impoverished regions of the world have questionable telephone service let alone Internet access. However, disparate access to the Internet is not a problem exclusive to the developing world. In fact, different levels of Internet accessibility are common to all nations (Warf, 2001).

Rather than discuss the global inequities of the information revolution, this research seeks to make a small jump. Although the United States is widely viewed as the leader of global
e-commerce, Internet technology, and Internet deployment, questions of accessibility within the United States abound. In fact, the very core of what defines “access” can be questioned.

For example, although the state of Alaska has the highest concentration of households “wired” to the Internet, does Alaska have the best access? Some would argue that Alaska’s relative distance from the major network access points and backbones inhibit data transfer and access speeds. On a smaller scale, although the city of East Palo Alto, California is located in Silicon Valley, do residents of East Palo Alto have easy access to the Internet? Many would argue that Internet access is sparse in marginalized communities such as East Palo Alto.

The objective of this research is to identify and define “access” to the Internet across three spatial levels: national, regional, and local. In doing so, this research hopes to uncover and explain why some locations are more “wired” than others and why location and geography still matter in the Internet revolution.

This thesis is organized as follows. A brief history of the Internet is presented in Chapter 2. This is followed by a review of the analytical research on Internet accessibility. Chapter 3 examines the mechanics of interconnection for Internet service providers, highlighting points of presence (POPs) and their role in city accessibility in the United States between 1997 and 2000. Also at the national level, Chapter 4 utilizes graph theoretic and aggregate network measures to explore city accessibility in the United States. At the regional level, Chapter 5 examines Internet presence and activity in the state of Ohio. Utilizing domain names as measures of Internet activity, an analytical framework for the detection of Internet activity clusters is presented. Chapter 6 segues between the regional and local levels of analysis by examining the differences in broadband infrastructure across Ohio. This includes a discussion on universal service and the Telecommunications Act of 1996. In addition, the uneven spatial distribution of broadband infrastructure is explained through a series of logistic regression models. At the local level, Chapter 7 examines spatial disparities in broadband access. Emphasis is placed on broadband digital subscriber line service, its spatial limitations, and the evolving spatial characteristics of the digital divide. Chapter 8 concludes the thesis with a summary.
CHAPTER 2

THE INTERNET

As noted in Chapter 1, the primary purpose of this thesis is to identify the fundamental differences in accessibility to the Internet in the United States across three different spatial scales. However, understanding the varying dimensions of domestic Internet accessibility requires a review of the Internet’s predecessors, ARPANET and NSFNET. Both of these early networks had a significant impact on the spatial structure of the current commercial Internet in the United States. Therefore, the purpose of this chapter is threefold. First, this chapter provides a historical overview of the Internet and its evolution from a distributed network, open to the public, to the privatized, commercial “network of networks” defining the Internet today. This is followed by a brief review of the analytical research on Internet accessibility, the digital divide, and the economic geography of the Internet. These subsections pay attention to the spatial context of the digital divide, the emerging digital economy, and the conceptual framework to which existing research contributes. Although the literature review in this chapter is somewhat brief, its purpose is to identify the major gaps in the literature on Internet accessibility and provide a foundation for further inquiry. Finally, a detailed treatment of existing analytical work on telecommunication access and its technical components is provided.

2.1 ARPANET to NSFNET to Internet

2.1.1 ARPANET

The technical foundation of computers linked to the Internet is the standard communications protocol known as Transmission Control Protocol/Internet Protocol (TCP/IP). First developed through a series of projects in the 1960s conducted by the U.S. Department of
Defense and their Advanced Research Project Agency, TCP/IP was the solution that allowed for a wide array of computer networks (designed by different vendors) to communicate between each other. In addition, TCP/IP allowed for a variety of different mediums such as satellite connections, wireless packet radio, and telephone links to communicate (Abbate, 2000; Rickard, 2000). As Gilbert (1995) suggests, the initial success of this communication protocol lied in its ability to deliver a few basic services such as file transfer, electronic mail, and remote logon.

The actual TCP/IP protocol is composed of layers. The Internet Protocol (IP) layer moves data packets between nodes by utilizing the four-byte, integer based destination address (IP address) system. The TCP layer verifies the correct delivery of data from each client (remote user) to each server. Because data can be lost in the intermediate network, TCP detects these losses and triggers packet retransmission until all data are received in the correct format (Gilbert, 1995). Finally, the sockets layer is a package of subroutines that provides access to the TCP/IP layers on computer systems.

In addition to the importance of the protocol platform, the topological foundations of network communications were also important. The Internet was conceived as a means of minimizing the vulnerability of the nation’s communication grid through the implementation of distributed network architecture. As Figure 2.1 illustrates, this type of communication network has many redundant pathways and offers significant advantages over decentralized and centralized networks that have aggregating nodes that are vulnerable to attack (Baran, 1964).

The Advanced Research Projects Agency Network (ARPANET) was the first experimental network that utilized TCP/IP and packet switching to link together a variety of computing facilities across the United States. Although TCP/IP was not implemented on the ARPANET until the 1970s, the first node on the ARPANET was activated at the University of California, Los Angeles in 1969. Eventually, active nodes were placed at the Stanford Research Institute, University of California at Santa Barbara, and the University of Utah. By 1971, ARPANET linked several clusters of sites in both California and the Northeast, with intermediate stops in Illinois and Ohio (Figure 2.2). Included in the 1971 network was a fully
Figure 2.1: Communication Network Topologies
Source: Baran (1964)
Figure 2.2: A: ARPANET in 1971
B: ARPANET in 1980

Source: Townsend (2001)
functional trans-continental link between Bolt, Beranek and Newman (BBN) (Boston) and RAND (Los Angeles) (Abbate, 2000). The ARPANET network of 1980 (Figure 2.3) was significantly larger, with four major trans-continental links in the United States. In addition, the majority of the network appears to maintain a decentralized topology, with a relatively high density of links in California and the Northeast. As expected, there also appears to be a strong correlation between interior nodes and military bases.

Major changes in the configuration of ARPANET began to take shape in 1983. The Department of Defense and the Defense Communications Agency decided to split ARPANET into two different networks. ARPANET remained public, but MILNET was be used to transfer all classified government communication. This split left 45 nodes on the ARPANET network. Eventually, this split led to the demise of the ARPANET network. It was replaced by NSFNET in 1987 (Townsend, 2001).

2.1.2 NSFNET

Once the National Science Foundation funded a series of national supercomputer centers in 1985, Internet development began to accelerate. Centers were located at Cornell University (Cornell Theory Center), University of Illinois (National Center for Supercomputing Applications), Princeton University (John Von Neumann Center), University of Pittsburgh-Carnegie Mellon (Pittsburgh Supercomputing Center), and the University of California, San Diego (San Diego Supercomputing Center). The purpose of the supercomputer center grants was to ensure that researchers within the university community had a fast and reliable method to exchange ideas and research. Gradually, the universities and researchers connected to NSFNET (56 Kbps) began to use electronic mail, file transfer, and newsgroups at an increasing level. Figure 2.3a illustrates the 56 Kbps NSFNET network in 1987. The most significant hub locations in the early NSFNET network are San Francisco, Atlanta, Washington, and New York. The locations of the supercomputer centers funded by the NSF are also evident in Figure 2.3.
Figure 2.3: A: NSFNET in 1987  
B: NSFNET in 1989  
C: NSFNET in 1991  
Source: Townsend (2001)
Eventually, with the rising popularity of the NSFNET, network traffic began to increase and the need for expanded capacity became clear (Harris and Gerich, 1996).

On July 24, 1988 the NSF network was completely shut down. A new network, created by Merit Network Inc., IBM, MCI, and the State of Michigan, upgraded the data capacity of the NSFNET to 1.544 Mbps T-1 lines that connected six regional networks. As Rickard notes (2000), “The NSFNET backbone was not the first network; its purpose was to interconnect the growing “regional” networks setup by various university systems.” Figure 2.3b illustrates the T-1 NSFNET backbone in 1989. Again, the topological structure appears to be very decentralized, although major aggregating nodes are found in San Francisco, Atlanta, Washington and New York.

As the number of nodes connected to the NSFNET continued to grow in the early 1990s, so too did network congestion. Eventually, the Merit/IBM/MCI consortium proposed a reengineering and upgrade for the network; increasing the network capacity from the existing T-1 (1.544 Mbps) lines to T-3 (45 Mbps) lines (Harris and Gerich, 1996). By 1991, the T-3 network expansion connected almost 3000 networks. The NSFNET T-3 backbone is displayed in Figure 2.3c. This network topology most closely resembles today’s Internet, with regional aggregation points in San Francisco, Los Angeles, Chicago, Atlanta, Washington, and New York. Although the T-3 network solved network traffic problems in the short term, as more private networks began to link to the NSFNET backbone, traffic began to increase (again), and overall quality of service began to decline.

To combat the surge of problems occurring on the existing network infrastructure, two major moves were made. First, the Commercial Internet Exchange (CIX) was created. The CIX included several private companies that connected through a router located in Santa Clara, California (although much of the traffic was still routed over the NSFNET). Second, plans to construct four Network Access Points (NAPs) were announced in February 1994. NAPs were to be located in San Francisco (operated by PacBell), Chicago (operated by Bellcore and Ameritech), Washington DC (operated by Metropolitan Fiber Systems), and Pennsauken, NJ (operated by SprintLink). The basic idea behind the four NAPs was to allow commercial
backbone providers and ISPs to interconnect at the four designated locations rather than connecting somewhere along the intermediary backbone. Additionally, the NAPs were based on high-speed local area network (LAN) technology so there were no restrictions on amount of usage. The NSF was hoping that these four network access points would also encourage the private sector to develop more national backbone (Harris and Gerlach, 1996; Frazer, 1996; Abbate, 2000; Rickard, 2000).

A related development occurred on September 20, 1995, when the National Science Foundation chartered the Federal Networking Council (FNC). The role of the FNC was to act as a forum for networking collaborations among Federal agencies, to meet their research, education, and operational mission goals, and to bridge the gap between the advanced networking technologies being developed by research agencies and the ultimate acquisition of mature version of these technologies from the commercial sector (FNC, 1995). In October, 1995, the FNC unanimously passed a resolution that formally defined the term “Internet” for the first time.

The Federal Networking Council (FNC) agrees that the following language reflects our definition of the term "Internet". "Internet" refers to the global information system that –

(i) is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons;
(ii) is able to support communications using the Transmission Control Protocol/Internet Protocol (TCP/IP) suite or its subsequent extensions/follow-ons, and/or other IP-compatible protocols;
(iii) and provides, uses or makes accessible, either publicly or privately, high level services layered on the communications and related infrastructure described herein.

(FNC, 1995)

On April 30, 1995, the NSFNET was formally decommissioned and the existing backbone was turned over to private interests for day-to-day operations. As Rickard (2000) notes, this is the day when the NAP architecture became the Internet.

2.1.3 The Internet

It is difficult to summarize the wide array of characteristics that describe the Internet today. Subsequent chapters (3 and 4) devote significant space to exploring many of the more
important functional characteristics, including interconnection and network configuration. However, there are a few additional points worth mentioning in this section that will complete the brief history already provided. First, the four network access points established by the NSF remain very important to the commercial Internet. There are only four of these major public access points in the United States, but thousands of national, regional, and local ISPs who need to interconnect to the Internet. Due to both financial and spatial constraints, interconnecting all of these ISPs to four NAPs is not possible. Therefore, 

**transit level providers** such as WorldCom or Sprint handle most interconnections at the NAPs (Gorman and Malecki, 2000) making network access points the most important (“top tier”) nodes of the Internet. Second, there are additional high-speed nodes for interconnection called Metropolitan Area Exchanges (MAE). MAEs are located in San Jose, Los Angeles, Dallas, Houston, Chicago, and Vienna, Virginia. Metropolitan Area Exchanges are very similar to NAPs, allowing backbone operators to interconnect and exchange traffic. As Rickard (2000) suggests, MAEs represent the second tier of interconnection options at the national level. Third, there are a variety of additional interconnection options known as Internet Exchanges (IX). As mentioned previously, the first IX was constructed in Santa Clara (CIX), however, there are other operational IXs in a wide variety of locations, including California (FIX-West) and Maryland (FIX-East). This brings the current total of major interconnection points in the United States to eleven (Rickard, 2000). A final point worth mentioning is that private exchange points have proliferated since 1997, meaning that backbone providers can interconnect at virtually any location where they share equipment rooms (Rickard, 2000).

The commercialization of the Internet has also impacted the network topology. Although the T-3 NSFNET backbone of 1997 served a geographically dispersed set of cities with high-speed connections, there are a significantly higher number of network links and their associated capacities in 1997 (Figure 2.4a). Finally, the period between 1997 and 1999 witnessed an intense build-out of backbone infrastructure, dramatically increasing bandwidth along the
Figure 2.4: A: U.S. Commercial Backbone in 1997
B: U.S. Commercial Backbone in 1999

Source: Townsend (2001)
commercial backbones (Figure 2.4b). However, as Townsend (2001) suggests, the gap between the top seven metropolitan areas and the remaining U.S. metropolitan areas remains.

2.2 Literature Review and Conceptual Background

As mentioned previously, the Internet is classified as a general-purpose technology. Because of its dramatic influence across a variety of economic and social frameworks, the conceptual foundations for studying the Internet are varied. One of the more effective conceptualizations of the Internet’s impact on both social and economic activity is that of Batty (1997), who suggests there are four different typologies of virtual geography, each representing different elements of the place and space created by computers and communications: 1) place/space – the original domain of geography that abstracts place into space using traditional methods; 2) cspace – abstractions of space into c(omputer) space, inside computers and their networks; 3) cyberspace – new spaces which emerge from cspace through using computers to communicate; 4) cyberplace – the impact of the infrastructure of cyberspace on the infrastructure of traditional place.

The primary focus of this thesis centers on the issues surrounding the typology of cyberplace. As Batty (1997) suggests, cyberplace consists of all the wires and equipment that comprise the networks which are embedded into manmade structures (e.g. roads and buildings). In other words, these are the physical and logical components of virtual space, within physical space (Batty and Miller, 2000). Although the physical components of cyberplace and their spatial distribution are a primary focus of this thesis, the intersection of these components, with more traditional measures of economic and technological development and the resulting impacts on the urban system (at all scales), are also of interest. The following subsections briefly review the literature concerning the intersections of cyberplace, access, and the emerging digital economy across different spatial scales, global, national, regional, and local.
2.2.1 Global Level Accessibility

Stressed throughout this thesis is the concept that Internet accessibility is set within a broader spatial context. At the macro-scale, there are a wide variety of important issues regarding Internet accessibility at the global level. As mentioned earlier, the ability for a city to access and disseminate information on telecommunication networks is important to their economic vitality in the information age, regardless of scale. A commonly used theoretical framework for understanding the convergence of economics and information technology is that of world or global cities (Friedmann and Wolff, 1981; Knox and Taylor, 1995). The core of the global cities argument suggests that it is impossible to understand the internal dynamics of cities like London, New York, and Tokyo without considering the much broader processes of global economic restructuring (Townsend, 2001). Knox (1995) suggest that world cities are the ‘basing points’ and ‘control centers’ for an interdependent network of financial and cultural flows. As Friedmann and Wolf (1982) first suggested, this represents a major development in the evolving global hierarchy, with cities shifting from manufacturing or processing based economies to service based economies (e.g. finance).

There are several different functional schemes for classifying cities in this framework. For example, Friedmann's (1986) hierarchy utilized a variety of attributes to classify global cities, including: concentrations of financial services, headquarters for multinational corporations, business services, manufacturing activity, transportation, and population. Knox (1995) utilized similar measures: 1) transnational business (measured by the number of global Fortune 500 headquarters located in each metropolitan area; 2) international affairs (measured by the number of NGOs and IGOs located in each metropolitan area; 3) cultural centrality (measured as the ratio of the city’s population to that of the largest, or next largest city. In a slight departure, Sassen (1991) utilizes measures of advanced producer services such as accountancy, advertising, insurance, and commercial law to create a hierarchical framework.
Friedmann (1995) synthesizes the spatial articulations of the global city framework, creating a four-tiered hierarchy: 1) Global financial clusters (e.g. London, New York, and Tokyo); 2) Multinational clusters (e.g. Miami, Los Angeles, Amsterdam); 3) National clusters (e.g. Madrid, Seoul, Sydney); 4) Subnational clusters (e.g. Seattle, Houston, Lyon). In a similar vein, Beaverstock et al. (2000) and Hall (1998) utilize a three-tiered approach to classifying cities.

Telecommunication and information technologies certainly play a major role in the processes that fuel global economic activity, interaction, and the emergence of the global city hierarchy (Taylor, 1995; Sassen, 1995; Castells, 1996). It is important to note, however, that network hierarchy is not necessarily related to the hierarchy of end-user services. As major network access points such as the U.S. NAPs and MAEs become more clogged with traffic, providers are moving to private exchanges for the purpose of peering (Barrett, 1998). These private peering points, or backbone hub locations, are not always located in major cities, but can be found in smaller suburban areas ringing major cities such as Chicago, San Francisco, and Washington DC. For example, Sprint maintains a private peering point in Relay, Maryland, a small municipality located adjacent to the Baltimore-Washington International Airport. Relay is 30 miles northeast of Washington and 8 miles southwest of Baltimore. More interesting is the major backbone presence that Sprint maintains in Roachdale, Indiana, which is located nearly 50 miles west of the Indianapolis city center. Clearly, there is not a substantial presence of highly technical or influential end-user services present in a place like Roachdale, when compared to major cities such as London or New York. Nevertheless, the OC-3 backbone link in Roachdale is the intermediate point between Chicago to Pennsauken (both NAP cities). It is the presence of these connections that provide global corporations the tools and abilities needed to coordinate spatially dispersed production networks and the distribution system needed to make information products available to the consumers of advanced services in world cities (e.g. finance, news, entertainment, and culture) (Townsend, 2001). Further, some authors would suggest the notion of flow is central to better understanding the dynamics of this emerging hierarchy (Castells,
1996). As mentioned previously, cities can no longer be viewed as discrete economic entities, but rather as nodes in a complex network of economic flows aided by telecommunication.

**Space of Flows**

Castells’ (1989, 1996) three-dimensional space of flows is one way to examine this complex array of economic activity between cities. As mentioned previously, Castells (1996) does not view global cities as discrete economic entities, but as processes “by which centers of production and consumption of advanced services, and their ancillary local societies, are connected in a global network” (1996: 380). Beaverstock et al. (2000) neatly summarize Castells’ (1996) theory, “(h)ence, cities accumulate and retain wealth, control, and power because of what flows through them, rather than what they statically contain, as is typically measured with attribute data” (2000: 126).

One approach for examining the space of flows in the world-city system is the use of international airline-passenger statistics (Keeling, 1995; Kunzmann, 1998). This provides at least one quantitative measure of interaction between nodes, better defining flow between cities. Beaverstock et al. (2000) suggest this measure is flawed due to the inability to filter out trips unrelated to global economic processes, such as tourism. In addition, the authors argue this method does not account for important intercity trips within countries (e.g. New York to Los Angeles). Therefore, both Beaverstock et al. (2000) and Taylor (2001) suggest that documenting the global location strategies of advanced producer-service firms is an effective alternative approach for describing world-city networks. In other words, by examining the distribution of offices and professional staff across the world-city system, a more effective geography of global economic networks and their underlying social networks is established. Taylor’s (2001) approach is decidedly more quantitative, formally specifying a modeling framework for evaluating these social/economic networks.
Global Gaps

What is clear from the various approaches creating hierarchical global city schemes is that consistent classifications are not possible. As Friedmann (1995) suggests, the world economy is too volatile to attach a fixed hierarchy to every city. Although the top tier of London, New York, and Tokyo is less likely to shift, more specialized second-tier cities engage in the equilibrating acts of “creative destruction” in an attempt to capture more of the command and control functions present in first-tier or other second-tier cities (Friedmann, 1995). As such, the most interesting questions concerning first-tier global cities pertain to both their relationship with cities belonging in the second and third tier of the hierarchy and the relationships between second and third-tier cities (Hall, 1998).

The major problem with the space of flows framework is the lack of information on flows between nodes of a network. As mentioned previously, airline passenger flows can be used as a surrogate for interaction between nodes. Similarly, social and economic networks of multinational firms are also used. Unfortunately, although aggregate statistics on telecommunication flows are available within countries (Telegeography, 2001), statistics on flows between countries and smaller entities such as cities are more difficult to acquire. Therefore, it is very difficult to determine the amount and type of information being funneled through such telecommunication networks. In this regard, the space of flows framework for research on telecommunications access is difficult to operationalize. More importantly, the flows of data packets over backbone networks do not necessarily represent destinations. Although a large amount of traffic flows through the Chicago NAP, the final destinations of such information is spatially disperse.

2.2.2 National Level Accessibility

The Internet is one of the most complex networks ever created. As such, efforts to analyze the structure and topology of the Internet can be difficult. In order to attempt an analysis, substantial simplifications of Internet structure must be made. The most common method for simplifying complex networks structures is the creation of a graph. Graphs are able to express
the relationship between nodes and their linkages in a variety of ways. In this particular case, cities are nodes and the fiber optic cables of the Internet serve as the linking mechanism. (A more complete discussion of graph theory and network topology is given in Chapter 4)

There have been several efforts to measure the topological aspects of the Internet using aggregate network analysis and graph theory. From a cyberspatial (Batty, 1997) perspective, Adams (1998) used combinatorial theory in conjunction with the basic tenets of graph theory to analyze the topology of virtual places (communicators and communication paths) and their relationships (opportunities and constraints) to social interactions. As the topologies of computer networks begin to mimic the topologies of familiar places, elements of similar social structuration are also shared. For example, Adams (1998) notes that e-mail (one-to-one or one-to-many) is a now familiar type of connection. “It resembles regular postal mail except that messages travel at a much faster rate… the main architectural archetype is the mailbox and the seclusion of the private room or office” (1998, 92). Another example is the computer forum (many-to-many, two-way). This is a basic chat room that allows for real-time discussion between users who might be separated (physically) by thousands of miles. Adams compares these rooms to auditoriums or central squares. Adams stresses the need to examine the complex social and political interplays between real and virtual worlds.

“If some aspects of computer networking, like other modern technologies, threaten to immerse us in anonymity, powerlessness, and an immoral, aestheticized space, disembedding us from the place based communities that once gave us a moral grounding, other aspects of computer networking evoke the possibility of something different: a social world that is global in scope and local in character.

(Adams 1998: 104)

Of more interest in this thesis is the work performed by Wheeler and O’Kelly (1999), which examines backbone topology and access through the application of aggregate network analyses to a national database of Internet backbone providers. Using network maps published in Boardwatch Magazine, the most comprehensive source of backbone data, Wheeler and O’Kelly (1999) utilized a variety of graph measurements to categorize the different levels of
connectivity including; the D-matrix, T-matrix, and the gamma index, to nearly 150 cities in the United States. This type of approach clearly fits within the cyberplace typology outlined by Batty (1997). Results indicate that the most accessible cities in the United States are located at major network access points. Moreover, the development of access points (which tend to yield higher levels of connectivity) hinged on the actual location of the cities, their regional status, and the levels of infrastructure development found there. Cities such as New York, Chicago, Dallas, San Francisco, Atlanta, and Washington DC were found at the top of the accessibility hierarchy.

Gorman and Malecki (2000) provide a more thorough discussion of the Internet provision industry, closely examining individual provider networks and their topology. Using a similar database from Boardwatch, the authors aggregate each city (nodes) to their appropriate Consolidated Metropolitan Statistical Area (CMSA), reducing the original 100 nodes to 60. The authors then incorporate the Internet links established by major US backbone providers (970), and calculate several graph-theoretic measures, including the cyclomatic number (network size), alpha index (redundancy), beta index (complexity), and gamma index (actual versus maximum number of links) for connectivity. Results suggest that cities located along the U.S. coastline (both east and west) display better levels of interconnectivity than those cities located on the interior. In addition, Gorman and Malecki (2000) provide empirical evidence explaining individual network performance in the context of a highly competitive backbone market.

Moss and Townsend (2000) provide a temporal overview of Internet growth between 1997 and 1999. The 1997 data included 29 networks and the 1999 data included 39 networks. Similar to the results presented by Wheeler and O’Kelly (1999), Moss and Townsend suggest that San Francisco, Washington, Chicago, New York, Dallas, Los Angeles, and Atlanta are the dominant ‘central nodes’ of the Internet in the United States. The authors also suggest that several interior cities are emerging as “hubs for new, large network links” (Moss and Townsend 2000, 41) and that the global cities of New York, Chicago, and Los Angeles display relatively weak network links.
Townsend (2001) modifies the global cities framework to reflect the emergence of smaller urban agglomerations displaying higher levels of Internet activity and interconnection than one would expect based on their population. This hierarchical framework of ‘new network cities’ ranks locations based on domain registration density, backbone capacity, and population. Townsend suggests new network cities are:

“highly prosperous regions, attracting skilled workers and the investment in infrastructure that is needed to sustain their growth, often at the cost of lost opportunities for other regions, and they are being organized into an exclusive and highly codependent economic system.

Townsend (2001, 57)

National Gaps

Perhaps the most significant gap in the literature at the national level is a standardized methodology for measuring city accessibility to the commercial Internet. All four papers reviewed in this section (with a cyberplace perspective) utilize different measures to compare the presence of Internet infrastructure, capacity, and city accessibility. Wheeler and O’Kelly (1999) utilize aggregate network measures for the entire commercial backbone system, Gorman and Malecki (2000) utilize graph theoretic measures for individual networks, Moss and Townsend (2000) utilize bandwidth to examine cities (nodes), and Townsend (2001) utilizes population, domain names, and bandwidth to develop a hierarchy of cities. Clearly, a standardized framework for analysis is needed. By establishing such a framework, one would have a basis for temporal comparisons of infrastructure growth, and a way to objectively compare city accessibility both in the United States and abroad.

Another gap in the literature on city accessibility concerns network interconnection. Gorman and Malecki (2000) provide a brief discussion on the processes of peering and transit for national backbone providers; however, the mechanics of interconnection and their spatial implications are not addressed. Specifically, the infrastructure required for interconnection to the commercial Internet is known as a “point of presence” (POP). Similar to the backbone links in the United States, the distribution of POPs are spatially uneven. A spatio-temporal analysis of POPs and their growth in the United States would provide a window to the ‘leading edge’ of
telecommunication infrastructure investment in a competitive ISP market, and provide insight into
the changing geography of city accessibility in the U.S.

2.2.3 Regional Level Accessibility, Internet Presence, and Activity

Each computer (host) on the Internet is identified by a set of unique integers called an
Internet Protocol (IP) address. This matrix of addresses allows computers to send and receive
information between each other (i.e. origin to destination). This information is transmitted along
fiber optic cables through a series of gateways and routers that depend on IP addresses to direct
the information packets to the appropriate locations. As Dodge and Shiode (2000, 44) note,
“(t)he IP address can be compared, in principle, to postcodes used in the real world to identify
locations for the delivery of letters and parcels”. For example, an IP address at Ohio State
University is 128.146.225.191. For the average user, remembering IP addresses proves
challenging. Therefore, each address also has a corresponding domain name. A domain name
is the character equivalent to this four-byte integer. For example, “orb1.service.ohio-state.edu” is
the companion domain name to the previously mentioned IP address.

The Internet Corporation for Assigned Names and Numbers (ICANN) is the non-profit
corporation that was formed to assume responsibility for the IP address space allocation, protocol
parameter assignment, domain name system management, and root server system management
functions previously performed under U.S. Government contract by IANA and other entities
(ICANN, 2001). ICANN also has three supporting organizations that “assist, review and develop
recommendations on Internet policy and structure within three specialized areas” (ICANN, 2001):
1) The Address Supporting Organization (ASO) is concerned with the system of IP addresses,
such as 128.9.128.127, that uniquely identify the Internet’s networked computers; 2) The Domain
Name Supporting Organization (DNSO) is concerned with the domain name system (DNS), the
system of names commonly used to identify Internet locations and resources. The DNS
translates hierarchically-structured, easy-to-remember names (like www.osu.edu) into IP
addresses that have been assigned to specific computers with unique machine names; 3) The
Protocol Supporting Organization (PSO) is concerned with the assignment of unique parameters for Internet protocols, the technical standards that let computers exchange information and manage communications over the Internet.

Numerous attempts have been made to examine the characteristics of IP address space on both the regional and national level. Dodge and Shiode (2000) examined the spatial patterns of IP addresses and the organizations connected to them in the United Kingdom. Using the “RIPE Network Management Database” the authors assigned geographic coordinates to the postal addresses that were provided for each entry. More specifically, the address information was gleaned from the administrative “contact” person for each computer listed. Dodge and Shiode believe that these contact points are analogous to Internet “landowners”. In essence, the computer servers are owned and registered by the contact person or their parent organization. Moreover, the authors are making the assumption that the computer is also located (physically) at the registered address. The results of their study indicate that the majority of the Internet space in the United Kingdom is located in a few urban centers. Not only did Central London and its surrounding suburbs display high densities, Nottingham, Cambridge, and Birmingham also contained a substantial number of IP addresses.

Dodge and Shiode (2000) are quick to note that this methodology has limitations. Many organizations own an entire block of IP addresses. Although all the addresses are registered to the home office (for example, London), many of the IP addresses may be allocated to branch offices around the country. Second, IP address space is constantly changing. Internet servers and IP addresses can discontinue service. Additionally, the registration addresses for the IP number can change. Therefore, all studies on the geographic distribution of IP addresses can only represent a single point in time.

Moss and Townsend, (1997a, 1997b, 1998) have written a series of articles on the geography of Internet domain registrations in the United States. Using the methodology of assigning geographic coordinates to the contact points of domain name registrations, the authors map and calculate some basic statistics on Internet presence and activity. In conjunction with
domain name counts, the Moss and Towsend (1998) also measured Internet backbone capacity (bandwidth) in their study. They note that there are some major discrepancies in the geographical characteristics of Internet presence and activity. The distribution of domain names in the United States is dominated by financial, government, and business centers. For example, they cite New York City as having 17,579 registered domains, followed by San Francisco at 7,718. They also note that many large, regionally oriented cities such as Houston, Phoenix, and Dallas contain large numbers of registered domains.

Zook (2000a) takes a slightly different approach to analyzing domain registrations in order to quantify Internet presence and activity. Rather than counting the number of domain names for a particular city, state, or region, Zook (2000a) examines the distribution of a specific domain name extension, (.com), in relation to population, employed civilian workforce, number of jobs, and business establishments at the national, regional, and MSA level. Zook (1998) makes an important distinction in the development of Internet related industries and the spatial concentration of Internet presence and activity. Instead of adhering to the basic tenets of product cycle theory, including the spatial concentration of innovation detailed in Malecki (1981), Zook (2000a) suggests there are multiple pathways toward the development of the Internet industry (presence and activity). These development trajectories are tied to a region’s pre-existing industrial and institutional structure. For example, the financial and publishing services found in New York encourage Internet development in much the same way that the entertainment industry does in Southern California, or the high-tech industries of the San Francisco Bay Area. Further, if there are no industrial, business, or educational “engines” driving the development of the Internet, Zook (2000a) suggests regional and local discrepancies in Internet presence can become profound.

**Regional Gaps**

One of the more significant gaps in the literature pertaining to Internet activity and presence is the lack of analysis at smaller geographical scales. Most work centers on
comparisons between countries (Zook, 2000b), regions composed of states, (NTIA 2000; Moss and Townsend, 1998) or individual states (Moss and Townsend, 1998). Sub-regional analysis centers on consolidated metropolitan statistical areas (CMSA) or metropolitan statistical areas (MSA) for comparative purposes (Moss and Townsend, 1997a; Zook 2000a). This work typically fails to include disaggregate data on smaller urbanized communities, thereby masking many interesting patterns at the sub-metropolitan level. Second, by understanding which communities and regions are more competitive, where information technology and Internet presence are concerned, policy analysts are better equipped to make decisions regarding initiatives for the deployment of Internet infrastructure, at all levels (local, regional, national). This is especially critical considering the increasingly competitive and commercialized industry for Internet access and its subsequent ramifications on infrastructure equity and the “digital divide”.

2.2.4 Local Level Accessibility

The “Digital Divide”, “Information Ghetto”, and “Falling Through the Net” (NTIA, 1995, 1998, 1999, 2000) are descriptive terms referring to lack of Internet service or accessibility for individuals within a community. Conceptualizing access at the local level can be difficult. For example, a micro-scale analysis might include explorations of individual accessibility to the Internet, defined by computer knowledge or familiarity with the WWW. Similarly, a local-scale analysis might include explorations of citywide infrastructure in an attempt to determine which neighborhoods contain sufficient infrastructure for Internet service provision.

Community Access and Electronic Villages

Broadly defined, an electronic village is a community-wide/local effort to create a virtual community (through Internet access) that compliments and improves the physical community where the electronic village is located. One of the premier electronic villages in the country is located in Blacksburg, Virginia. The Blacksburg Electronic Village (BEV) was conceived in 1991 as an outreach effort by Virginia Polytechnic Institute and State University partnered with the town of Blacksburg and the local telephone company, Bell Atlantic (now Verizon). The goal of this
partnership was to extend network access to every citizen in Blacksburg. By 1993, a fiber backbone was installed and all the digital switching equipment was in place. Initially, dial-up access was the only way to connect to the network, but in 1994, ISDN and Ethernet connections were made available. Today, more than 75% of Blacksburg’s 60,000 residents are using the Internet on a regular basis (BEV, 1999; Yahoo, 1998).

**Local Infrastructure**

Although electronic villages are becoming more popular, there are many other examples of towns and smaller localities that are simply building network access. For example, the city of Lusk, Wyoming (pop. 1,504) secured a grant of $295,000 to create Internet access for its residents. Largely agricultural, and home to a large number of retirees (located 100 miles west of Casper and 100 miles north of Cheyenne), Lusk proves that simply wiring a town does not create an active online community. Although the schools are frequent users of the Internet, the network sees limited use from other members of the community (Yahoo, 1998). One final example of local infrastructure improvements fostering network access can be found in Barbourville, Kentucky (pop. 3,300). Located in the Cumberland Mountains (approx. 80 miles south of Lexington, KY, and 70 miles north of Knoxville, TN), Barbourville is a rural community with many undereducated and unemployed residents. However, after spending over $2 million to construct a fiber optic network, the investment is finally paying off. Not only do the existing businesses and public schools have instant access to information, the Immigration and Naturalization Service who recently located a call center in Barbourville (employing 300) benefits from quality telecommunicative infrastructure (Columbus Dispatch, 1999).

Unfortunately, with every success story, there are other communities struggling to get connected. Surprisingly, the communities of Palo Alto and East Palo Alto, California are such examples. Located in the heart of Silicon Valley and home to Stanford University, Palo Alto is having problems getting “wired”. In 1996 and 1997 the city constructed a fiber optic ring (backbone) to improve community-wide access. This has proven to be a poor strategy. The
connections to the fiber ring are very expensive and only a few large businesses have enrolled as customers. Moreover, the fiber ring cost almost $2 million to construct and has only earned $300,000 as of March 1999 (Oram, 1999). Critics questioning the merits of this publicly funded project in Palo Alto suggest that residents of a community where median housing values exceed $450,000 can afford to pay privately held ISPs for Internet access. However, the fiber optic ring is not the only problem facing Palo Alto and its surrounding communities. To compound matters, East Palo Alto is impoverished (80% of the residents receive public assistance), undereducated, and has high unemployment rates. Many critics believe that the money spent on wiring residents in Palo Alto could be better spent on making Internet access available to communities that cannot afford it, such as East Palo Alto. Unfortunately, the focus of this debate is centered on something that the “Information Superhighway” and the Internet were supposed to erase, distance and borders. East Palo Alto is a separate municipality that is located across the county border from Palo Alto. Clearly, there is no incentive to include East Palo Alto in a fiber ring constructed and built by its neighboring city. In fact, California state law prohibits a municipality such as Palo Alto paying for the wiring of surrounding communities (Oram, 1999).

**Sociodemographic Patterns**

The previous illustrations demonstrate that simply wiring a community is not enough to insure equal access for the individuals or households. In fact, the current demographic patterns of Internet access display some striking disparities regarding who is “on” the Internet and who is not. Starting in 1995, the NTIA has surveyed and measured US household connectivity to the telecommunications and information infrastructure. The surveys measure telephone, computer, and Internet penetration rates. Results indicate that penetration levels vary substantially across the United States, reflecting differences in income, education, household type, and geography. For example, even the penetration rate of a mature technology such as the telephone is lagging in some areas. The telephone penetration rate of 87% in New Mexico is significantly below the 94% national average.
It is an easy leap from discussions on telephone penetration to a discussion on Internet access and usage. Today, telephone lines and dialup modems remain the most common way to access the Internet. A recent NTIA (2000) survey documents the differences between individuals through the examination of their demographic and socioeconomic characteristics. As one might expect, Internet usage is directly related to one’s income level. For example, 18.9% of the individuals earning under $15,000 use the Internet. In contrast, almost 70% of the individuals who earn $75,000 or more use the Internet. Moreover, the location where one accesses the Internet also correlates to income. For example, individuals with incomes below $35,000 use the Internet outside the home more often than those with incomes higher than $35,000. Differential access and usage rates are also evident through the analysis of race/origin. Both Whites (50.3%) and Asians (49.4%) use the Internet more than Blacks (29.3%) or Hispanics (23.7%). Even more striking (and pertinent to this thesis) are the differences in Internet usage across space. For example, Internet usage (regardless of race or income) is significantly lower in rural areas. When race is considered, urban Whites are on the Net the most (48.3%) while rural Blacks are on the Internet the least (19.9%). Extending the geographical theme further, home Internet access varies significantly by region and state. For example, Alaska (in many ways an anomaly) leads the home Internet access pack, with 55.6% of the households “wired”. In contrast, Mississippi is last among the fifty states with only 26.3% of the households wired (NTIA, 2000).

Local Gaps

Perhaps the most significant gap in the literature concerning local Internet access pertains to the spatial distribution of telecommunication infrastructure and its impacts on Internet service. First, very few studies have documented the uneven spatial distribution of telecommunication infrastructure at the local level. With the Telecommunications Act of 1996, deregulation has spurred massive investment from the private sector, but similar to the national and regional levels, local market characteristics create situations where certain locations are more attractive than others for investment. As profit seeking firms, telecommunication providers
select both local and sub-local markets where profits can be realized, ignoring markets where returns on investment are low. Second, because of deregulation, telecommunication providers are no longer required to provide equal service to all customers. Thus, certain segments of a local market are able to receive emerging Internet access technologies such as digital subscriber lines and cable, while other segments of the market cannot.

There is a clear need to document these disparities in access at the local level. More importantly, because there are a wide variety of spatial limitations to the provision of emerging access technologies such as xDSL and cable, there is a need for the development of a modeling framework that can evaluate issues of infrastructure equity in a profit-dominated and competitive Internet provision market.

2.3 Summary

Since the inception of ARPANET, NSFNET, and the commercial Internet, a great deal of research has been conducted in an effort to better understand the spatial ramifications of this technology. Proponents of the urban dissolution framework suggested that the Internet would facilitate a convergence between time and space and that economic decentralization would soon follow. Critics of the urban dissolution framework argue that relative location continues to play a pivotal role and that agglomeration economies are still vital in the emerging digital economy.

Implicit to all of this research is the concept of access and the role that the physical articulations of the Internet and other telecommunication technologies play in the digital economy. At the national level, further work is needed to evaluate the impact of a city’s location, relative to the topological structure of the commercial Internet, as it relates to the overall availability and quality of Internet access. Similarly, a more thorough snapshot of a city’s ability to interconnect to the commercial Internet, as dictated by the presence POPs, is needed. These research avenues will help uncover many of the more perplexing issues related to metropolitan economic development in the emerging digital economy here in the United States.
At the regional level, more research concerning the factors spurring Internet activity and presence is required. Although much of the existing literature documents the importance of domain registrations as indicators for Internet related activity, very little of this work places such activity in context. Is Internet activity related to existing infrastructure? – Regional economic engines? – The regional workforce? More importantly, a standardized analytical framework for the detection of activity clusters is also needed.

Finally, more analyses of telecommunication infrastructure and the role it plays in Internet access and quality are needed to better understand the spatial ramifications of the digital divide at the local level. This is especially true when new access technologies such as xDSL are concerned. One key avenue of research in this area is to investigate the spatial gaps in xDSL service coverage at the sub-metropolitan level. Not only with this provide a standardized analytical framework for modeling service coverage, it can provide a window from which policy analysts can address the challenges for equitable service provision in an increasingly privatized market for Internet access.

In the following chapters, several gaps in the literature will be closed. This research should not only reinforce the notion that location does matter in the new “information economy” and the Internet, but that definitions of access to the Internet hinge on a spatial context.
CHAPTER 3

POINTS OF PRESENCE AND CITY ACCESSIBILITY TO THE COMMERCIAL INTERNET

The evolution of the Internet from the original ARPANET network developed by the US Department of Defense in the late 1960s to today’s massive array of telecommunication hardware (fiber optic cables, routers, switches, etc.) was documented in Chapter 2. Estimates by Matrix.Net (2001) suggest 109,574,000 computer hosts currently exist worldwide. In fact, between January 1998 and January 2001, the number of hosts grew nearly 270%, indicating that the Internet roughly doubles in size each year (Figure 3.1). In addition, Nielson NetRatings (2001) estimates 163 million households have Internet access in the United States alone.

This massive growth in telecommunication networks is attributed to a variety of factors. The deregulation of the telecommunication industry both in the United States and abroad has largely commercialized network access (Guldmann 1999, Schiller, 1999). This global trend toward the privatization of telecommunication networks has a significant geographical component. Without the cross-subsidization plans present in a regulated telecommunications market, commercial providers in a deregulated and competitive market simply respond to the pressures of supply and demand for their services (Gorman and Malecki 2000). Locations where demand is high (major urban centers with high population densities and significant economic activity) receive the majority of infrastructure investment, while smaller cities and rural areas often struggle to establish even the most basic telecommunication services (NTIA and RUS, 2000). For example, many backbone providers are rapidly expanding the geographic reach of their services by opening additional points of presence (POPs) in select metropolitan areas, but few

\footnote{Acknowledgement: This chapter represents an expanded and revised version of a paper to appear in \textit{Professional Geographer}, co-authored with Morton E. O’Kelly.}
Figure 3.1: Internet Host Growth - 1993 - 2000

(Source: Internet Software Consortium - http://www.isc.org)
are being opened in rural areas. These points of presence are locations where Internet service providers (ISP) maintain telecommunication equipment that makes network access possible. This usually takes the form of a switch or router that allows local, regional, or national traffic to gain entry, or continue its journey on commercial Internet backbones.

In terms of economic development, activity, and competition, the spatial disparities in telecommunication access and infrastructure investment are critical. Graham and Marvin (1996) provide an extensive review of these issues, discussing the locational advantages of urban centers in the information economy. The authors highlight emerging agglomeration economies, both categorically and spatially. For example, not only do “global command centers” such as New York, London, Paris, and Tokyo dominate their respective countries in telecommunication infrastructure, these cities are also centers for financial services, transportation, and education. This domination of these world cities, where telecommunication infrastructure is concerned, is not without historical context. Larger population centers have always been interconnected, whether by rail, road, telegraph, or phone. The metamorphosis of these cities into telecommunication centers is partially explained by the economics of converting existing telecommunication infrastructure in place for voice (plain old telephone service) to data. Simply put, it was less expensive to update the existing infrastructure in these cities than to build a completely new network (Graham and Marvin, 2001). Graham and Marvin (1996) also suggest that the locational flexibility afforded by telecommunications is creating a significant shift in the economic geography of a networked world. Many have argued that economic and social activities are no longer constrained by distance because telecommunication networks have made space relatively meaningless where interaction is concerned (Brunn and Leinbach 1991; Castells 1989; Cairncross 1997). Although the aforementioned work addresses many of the conceptual issues regarding the impact of the Internet on economic restructuring in the new economy, much of this research fails to incorporate systematic empirical investigations of telecommunication investment, its spatial patterns, and the impact of such investment on the local or regional economy.
The purpose of this chapter is to provide a longitudinal analysis of telecommunication infrastructure investment for the commercial backbone industry for the United States. Although many different types of infrastructure exist (e.g. fiber optic backbones, cellular towers, etc.), this chapter highlights the establishment of points of presence (POPs) on commercial backbone networks. By documenting the changing spatial distribution of commercial POPs in the United States, we can begin to evaluate the urban and economic factors spurring telecommunication infrastructure growth and investment. Results indicate that several hot-spots of Internet presence have emerged over the past three years in the United States. Cities such as Miami, San Diego, and Portland that were initially lagging behind early strongholds of POP presence (e.g. New York, Washington DC, and San Francisco) have quickly recovered and are now home to numerous POPs for national backbone providers.

The remainder of this chapter is organized as follows. Section 3.1 briefly summarizes the geographical literature on telecommunication access, equity, and economic development as it relates to telecom infrastructure, the commercial Internet, and the “global cities” framework discussed in Hall (1998) and Taylor (2001). Section 3.1 also describes the process of interconnection between network providers, including a thorough look at interconnection points and a brief discussion on network peering. Section 3.2 describes the longitudinal data set and methods used for analysis. Section 3.3 presents results. Section 3.5 contains a discussion and concluding remarks.

3.1 Geography and the Networked Economy

The business of interconnection in the US commercial backbone industry is a growing one. Complex in nature, interconnection for telecommunication networks is not only facilitated by technology, but also geography. Historically, the value of telecommunication networks is tied to their geographic reach (Caristi, 2000). Networks with large “footprints” are able to serve a wider array of customers and ultimately benefit from a larger return on investment. As mentioned previously, simply extending the reach of fiber optic backbones is not enough.
Telecommunication providers must provide “access ramps” to these backbones in order make network access possible. Backbone points of presence are the most efficient way to create such access ramps. Points of presence usually take the form of an electronic switch that is located in a building (often referred to as a wire-center) that accommodates POPs for a wide variety of ISPs and their affiliated networks. Figure 3.2 illustrates a potential hierarchical configuration of POPs, highlighting their spatial context. At the national level, POPs act as hubs for originating traffic seeking long distance transit on the Internet. In this sense, these points of presence are serving as agglomeration points and access ramps for much of the local and regional traffic on a network seeking long distance transit via the Internet. Second, POPs contain the hardware that delivers terminating long distance traffic for backbone operators. In essence, POPs serve as delivery hubs for locally and regionally destined traffic. Finally, points of presence serve as major intermediary points for the delivery of Internet data packets. In this case, POPs are locations where long distance traffic can switch provider backbones for additional long distance transit.

There are several additional facts concerning points of presence that need elaboration. First, Figure 3.2 illustrates the hierarchical nature of POPs. As Downes and Greenstein (1998a; 1998b) suggest, the US commercial ISP market is largely comprised of thousands of small geographically dispersed markets for Internet access. Within these markets, the actual number of ISPs and the characteristics of the points of presence they operate can vary widely. Cukier (1998) and Gorman and Malecki (2000) suggest that ISPs can be classified into four different categories: (1) transit backbones; (2) downstream ISPs; (3) online service providers and (4) web hosting. For example, a large ISP such as WorldCom is classified as a national backbone provider (transit). In fact, WorldCom maintains over 2,600 connections nationwide (McCarthy 2000). Many local and regional providers (downstream ISPs) purchase the right to use WorldCom POPs as their gateway to the commercial Internet and the WorldCom backbone. This leads to a second important point, although all ISPs provide Internet access, they do not

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2 Actual configurations are difficult to obtain due to the proprietary nature of these data. However, some providers such as Genuity provide lists which illustrate the differences between their POPs – some cities are served by OC-48 POPs while others are only served by T-1 POPs. [http://www.genuity.com/infrastructure/maps.htm](http://www.genuity.com/infrastructure/maps.htm).
Figure 3.2: Interconnection and Geography
necessarily provide backbone services. For example, national Internet service providers such as MindSpring provide Internet access through a POP. However, these online service providers only manage POPs that connect consumers dialing in through an analog modem; the actual transit of data packets is left to national backbone providers such as WorldCom or Sprint (Gorman and Malecki 2000). The third and final point needing elaboration concerns the spatial distribution of POPs. As Downes and Greenstein (1998a) demonstrate, there is a strong correlation between locations with low population densities and no Internet service providers (approximately 20% of the US population lives in these underserved locations). Therefore, the authors suggest the presence of multiple POPs, whether national, regional, or local tier, is an urban phenomenon.

3.1.1 Global Cities

The role of urban centers in the networked economy has generated significant debate. Ironically, even as Cairncross (1997) proclaimed the “death of distance” and the movement of economic activity to suburban locations, telecommunication investment to facilitate a diffuse economic geography was booming in the core of select “world cities” (Castells 1996; Taylor 2001). Sassen (1994) suggests this accumulation of telecommunications infrastructure is essential for linking “command and control” centers with the global economy. Therefore, instead of eliminating the effects of distance and marginalizing location, the networked economy has reinforced the role of major urban centers in the global hierarchy (Townsend 2001; Gorman 2001; Taylor 2001).

As mentioned in Chapter 2, typologies of global, national and regional cities serve the general purpose of describing the way cities vary in size and function. By adapting Hall’s (1998) typology, three classes of cities are outlined for the United States: 1) global; 2) national; 3) regional. Global cities focus on specialized information services such as financial services, medical services, educational and health services, and tourism (Raines 2000). These information intensive cities benefit from large agglomerations of similar businesses, and possess a vibrant
downtown core with a high density of buildings and population. Examples of global cities within the U.S. include New York and Chicago (Townsend 2001). National Cities closely resemble global cities but operate at a smaller scale, failing to offer global-level specialized services across multiple sectors (Raines 2000). Nevertheless, national cities such as Atlanta (media services), Los Angeles (entertainment), and Washington DC (government) remain important nodes of the digital economy and can often approach global city status in certain sectors of the economy (Raines 2000). Regional Cities are smaller in sphere and influence, operating as the market centers through which many local goods and products flow (Raines 2000). Cities such as Cleveland, Milwaukee, and Columbus can maintain a national level specialization, but these types of cities are no longer the sole hub of economic activity in a region. In many cases, suburbanizing areas or edge cities often contain more leasable office space than the downtown core (Garreau 1991).

There are several factors that continue to attract economic activity and telecommunication infrastructure to urban centers at all three levels. In order to better understand these forces, one need only look at the nature of the information economy. Several authors such as Castells (1996), Moss (1998), and Zook (2001) suggest that knowledge and the manipulation of information is the fundamental driver of the digital economy. Moreover, telecommunication networks are key components because they allow for the fluid transport of information, knowledge and communication – the valuable goods of the information economy (Moss and Townsend 2000). This makes the separation of telecommunication infrastructure (e.g. fiber optic networks and POPs) and economic activity in urban areas difficult.

By identifying spatial disparities in telecommunication infrastructure in the United States, this chapter provides a window into the evolving urban and economic landscapes fueled by the Internet. Several studies have already suggested that the spatial distribution of telecommunication networks and their related capacities are uneven (Wheeler and O’Kelly 1999; Gorman and Malecki 2000). In fact, both of these studies found that communications infrastructure in the United States is generally aggregated in the largest metropolitan regions (e.g.
New York, San Francisco, Chicago, Washington DC, and Los Angeles), suggesting a national hierarchy very similar in nature to the previously outlined framework; with a handful of cities exhibiting dominant shares of telecommunication infrastructure and related economic activity.

This is not to say that more traditional factors shaping economic processes are any less valid. For example, empirical work by Simmie (1998) suggests that the clustering of innovative industries (including software) is still driven by a combination of local production factors, high quality human resources, high levels of knowledge and information, and venture capital. Similar evidence, with an emphasis on e-business location and domain name activity is presented in Gorman (2001) and Zook (2000a).

Although previous work indicates several metropolitan areas have emerged as strongholds of telecommunication infrastructure, there is increasing evidence that many regional cities are simultaneously benefiting from significant telecommunication infrastructure investment. With that in mind, it is important to explore the factors spurring this growth. First, how has the telecommunicative landscape evolved between 1997 and 2000? Second, why have cities like Miami, Portland, Nashville, Milwaukee, and Tucson seen an infrastructure building boom? Is this boom simply a function of supply and demand, or a more complex process that is fueled by a variety of contextual elements unique to these cities and their local geography? Because points of presence are the access ramps to the commercial Internet, their spatial distribution is a key component in evaluating telecommunication accessibility for cities. The following section provides specific details regarding the role of transit level POPs on the commercial Internet, the business of interconnection, and the impacts of points of presence on accessibility. This background information provides an important foundation for better understanding the Internet and infrastructure investment in a competitive environment.

3.1.2 Interconnection, POPs, and Peering

As mentioned previously, the business of interconnection is booming. At the national level, interconnection points for the existing commercial backbone industry in the United States
can take a variety of forms. Currently, the core of the commercial Internet exists at four network access points (NAP). Originally constructed in 1995, the four NAPs are located in San Francisco, Chicago, Washington DC, and Pennsauken, NJ (New York). The purpose of these NAPs was to allow commercial backbone providers and Internet service providers to interconnect at four designated locations rather than connecting somewhere along the intermediary backbone (Rickard 2000). Further, the network access points are designated as public peering points where all backbone operators (regardless of size) are allowed to interconnect (Rickard 2000). Additional options for interconnection are available at metropolitan area exchanges (MAE) or public/private Internet exchanges (IX).

It is important to note that the NAPs, MAEs and IXs do serve as the point of presence for many carriers in a given metropolitan area. For example, Table 3.1 illustrates all the backbone network providers using the Dallas, Texas MAE located at 1950 North Stemmons Freeway. This locational specificity is highlighted for several reasons. First, network access points and metropolitan area exchanges do not perform the routing functions for the co-located Internet service providers (mae.net 2000). To clarify, the routers are owned and managed by ISPs but are connected and housed in the MAE or NAP. In fact, routers are the only pieces of hardware connected to the metropolitan area exchange or network access point. Therefore, Internet service providers must build their own fiber optic backbones to transit data between MAEs or other network access points (mae.net 2000). The trunks of fiber optic cable emanating from MAEs or NAPs are often referred to as “the first mile”. Second, metropolitan area exchange facilities also function as connecting points for corporations seeking access to the commercial Internet. The companies seeking interconnection must either build or lease the fiber optic cable running from their building to the MAE. This is usually accomplished by leasing a line/bandwidth from commercial ISPs (backbone providers) maintaining a presence in the MAE.

The operational nature of network access points and metropolitan area exchanges highlights another key element of interconnection, peering. The relationship established between two or more ISPs for the purpose of exchanging traffic directly between networks is known as
“peering”. As suggested previously, POPs represent the specific geographical locations where this type of traffic exchange and interconnection takes place. Therefore, because backbone providers frequently establish points of presence in NAPs, MAEs, and IXs, these are the locations where peering takes place. To use a simple analogy from transportation, imagine a series of interstate highways (fiber optic backbones) converging at a single cloverleaf junction. At this location, traffic (data packets) are allowed to continue their journey on the existing highway (backbone 1) or they may switch highways (backbone 2, 3, … n) using directional information provided by the interstate signs (routers). Finally, imagine a series of interstate highways where only select sets of routes are open for travel from the cloverleaf (points of presence within a NAP, MAE, IX); these routes represent peering or transit agreements between providers. Therefore, if one reexamines Table 3.1, these data suggest that any of the providers listed have the opportunity to peer or provide transit for each other depending on their agreements. In other words, although the POP is necessary in this case, it is not always sufficient.

The previous analogy highlights several of the most important characteristics of POPs. First, if a region is lacking transit level POPs, interconnection for large corporate customers, local Internet service providers, and households is difficult. This is clearly an issue of accessibility. For example, although a massive fiber optic backbone may run adjacent to Interstate 40 in Amarillo, Texas, unless there is a POP in place, its communication capacity cannot be tapped. Therefore, one can argue that agglomerations of POPs in metropolitan areas are a significant benefit. Not only does agglomeration provide more choice for interconnection at all spatial levels, it is also indicative of significant infrastructure investment and an increased market demand for access. Metropolitan areas without agglomerations of POPs can suffer in a variety of ways. For the past few years, Boardwatch Magazine and Keynote systems have been monitoring and evaluating the performance of select national backbone providers in the United States (Boardwatch 2000). The resulting performance index constructed through these evaluations is indicative of download performance.

3 The Dallas MAE participant list is clearly missing many of the largest ISPs such as Sprint, Qwest, and AT&T. This is partially attributed to the poor performance of MAE switches and general overcrowding of MAEs (Barrett, 1998). Instead, many of the larger ISPs have opted for private peering points instead of the public MAEs.
1. Broadwing
2. CAIS Internet
3. Cleardata.net
4. CommTech
5. Cogent Communications
6. Digital Island Inc.
7. Epoch Communications
8. Genuity
9. ICG Communications
10. Info Avenue Internet Services
11. Intermedia-Digex
12. IP Quest
13. NetRail
14. Primus
15. RoadRunner
16. Verado Holdings
17. Winstar Communications
18. XO Communications

Table 3.1: MAE Participants in Dallas, TX *
* Source: http://www.MAE.net
times for Web pages and backbone performance under network stress (high traffic). Results clearly indicate that backbone performance between providers can vary quite widely (Figure 3.3). Therefore, if an end-user is operating from a very isolated metropolitan area, with limited POPs, connecting to poorly performing networks, questions concerning metropolitan access and economic well-being become important.

3.2 POP Data and Methodology

Spatially, the analysis in this chapter will focus on the 48 contiguous U.S. states. Network provider “point of presence” data for 1997, 1999, and 2000 will be utilized for analysis. These data are compiled every year by Boardwatch Magazine, the leading source of information on backbone providers, and Internet service providers in the United States. Similar data sets have been used extensively in previous research on the Internet with much success (Wheeler and O’Kelly 1999; Malecki and Gorman 2000;).

It is worth mentioning that the number of network providers included in Boardwatch Magazine varies from year to year. This reflects the rapidly expanding backbone provider industry. However, recent trends at the national level are of network consolidation or bankruptcy. For example, between publication of the 1999 and 2000 directories, seven providers filed for bankruptcy and four were purchased and incorporated into competing networks (Tally 2000). This chapter utilizes 31 networks listed in 1997, 43 for 1999, and 41 for 2000.

The enumeration of POPs for analysis is a somewhat tedious process. Boardwatch provides a network map for all backbone providers in each edition. Included on these network maps are points of presence (denoted by cities). Most providers also include a separate list of major U.S. backbone hub cities. It is the combination of network map POPs and hub city lists that are enumerated and utilized for analysis in this chapter.

Once the POP locations (city) for each network were entered into a spreadsheet, a “pivot-table” function was employed to create a summation matrix for every city that had at least one

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4 1998 data were unavailable
Figure 3.3: Commercial Backbone Performance Index
(Source: Keynote Systems and Boardwatch Magazine, 12th Edition)
POP in the US. The resulting table contained nearly 2500 POP entries. After eliminating duplicates, developing a standardized naming convention for each city, and assigning each observation to the appropriate year, a comprehensive database of POP presence was created. This database accounts for POP locations in nearly 220 US cities. These data were then imported into ArcView, a commercial GIS package, for analysis.

There is some debate as to the appropriate level of analysis of POPs and telecommunication clusters in recent work. Some approaches utilize city level analyses of Internet presence and access (Wheeler and O’Kelly 1999). Criticism of this approach focuses on the fact that there is an increasing prevalence of metropolitan fiber rings that interconnect larger metropolitan areas. As such, other work utilizes city level data aggregated to Metropolitan Statistical Areas or Consolidate Metropolitan Statistical Areas (MSA/CMSA) (Malecki and Gorman 2000; Moss and Townsend 2000). This chapter explores both options for analysis and compares accessibility results with and without aggregation.

3.2.1 Limitations

Similar to other analytical studies on the Internet, the picture presented in this chapter is fleeting. Given swift advances in telecommunication technology and the rapidly expanding market for backbone service, the results presented in this chapter must be considered as a “snapshot” of city accessibility. Compounding matters is the competitive nature of the backbone market and proprietary nature of quality data sets concerning POPs and peering. Although backbone operators are somewhat forthcoming with basic data on POP locations, the information contained in Boardwatch is often a “stripped-down” version POP locations when compared to the network maps on provider Web sites. For example, the PSINet network is very generalized in Boardwatch when compared to the network map available from the PSINet website. Therefore, the data used in this analysis are largely based on the convenience of a unified source.

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5 For a thorough spatial definition of communities belonging in each MSA/CMSA, see http://www.census.gov/population/www/estimates/metodf.html
(Boardwatch). As such, this standardized framework and format allows for an unbiased longitudinal analysis of POP data.

### 3.3 Accessibility to the Commercial Internet

#### 3.3.1 City Accessibility

Figure 3.4 illustrates the dramatic changes in POP presence for US cities between the years of 1997 and 2000. There are several trends worth exploring in these data. The 1997 panel illustrates the tendency for backbone providers to locate POPs in the largest US cities. One can argue that this pattern mimics market demand for backbone services. For example, Chicago, Washington, Los Angeles, New York, Dallas, Atlanta, Houston, and San Francisco, all have a very significant presence of POPs within their city limits. Further, all of the top cities, with the exception of Atlanta host a NAP or MAE. This attests to the importance of NAPs and MAEs as major aggregation points for national backbone providers. As Wheeler and O'Kelly (1999) note, Atlanta’s high level of accessibility can be attributed to Atlanta’s historical role as a gateway to the South.

The panel for 1999 displays some drastic changes in the POP landscape. Aside from more backbone providers being present in the data set (43 in 1999 v. 31 in 1997), several cities begin to emerge as major points of presence for backbone providers. Although the “Big 7” of Chicago, New York, Washington, Los Angeles, Dallas, Atlanta, and San Francisco remain firmly entrenched at the top of the rankings, Seattle, Boston, Denver, Kansas City, and San Jose emerge as significant centers of POP deployment. Seattle, San Jose, and Boston are all major research hubs and are often referred to as corporate strongholds for the digital economy (Zook 2001; Gorman 2001). Not surprisingly, these areas tend to have high levels of demand for backbone services. POP presence is a natural reflection of this demand. Further empirical proof of market demand for these cities is illustrated by the presence of domain name registrations and corporate office locations (Zook 1998; Zook 2000a; Moss and Townsend 2000). In addition, San
Figure 3.4: POP Counts by City
Jose is also home to MAE-West, a major interconnection point for backbone providers. Although attempting to explain the diffusion of POPs in Denver and Kansas City is more difficult, when one considers the driving force behind POPs (presence of network backbones), it is clear that both Denver and Kansas City have certain geographical advantages. For example, both cities are centrally located and act as the major regional service centers in their respective areas. Further, both cities straddle several major interstates, including I-70. Considering that Internet backbones often “traverse private and public rights-of-way, often alongside highways or railroad lines, to connect metropolitan areas across the country” it should be no surprise that major cities along the I-70 corridor such as Denver and Kansas City have a high presence of POPs (Moss and Townsend 2000). Further, the city of Denver is rapidly becoming the center for broadband technology development. In fact, with the recent restructuring of AT&T into four separate businesses, AT&T’s broadband division announced that Denver was their official headquarters. Denver has also served as the home-office location for a variety of cable operators, including Media One, Jones Intercable, and TCI. In addition, Denver is home to the fourth largest telecommunications provider in the United States, Qwest.

The panel for 2000 (Figure 3.4) illustrates the most current information available for POPs in the United States. Although many of the same patterns remain, there are several significant developments at the city-wide level. First, cities such as Orlando, Tampa, and Miami are finally showing signs of a significant POP presence. From a network standpoint, the relatively slow growth of POPs in these major cities is not remarkable. Virtually all of Florida is isolated from the core backbones of the Internet because of its location. Historically, it has been difficult to connect cities such as Miami because of their geographic isolation. Not only is Miami one of the most southerly cities in the US, its relative remoteness on a peninsula and its lack of a major peering point (NAP or MAE) make connection and accessibility a challenge. This “end of track” phenomenon was mentioned in connection with the explanation of early connectivity ratings for

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[^6]: Currently, BellSouth is planning to install the first optical NAP in the United States for the FloridaMIX (Intercoast.com, 2000).
cities like Miami (Wheeler and O'Kelly 1999). Similarly, although a city such as San Diego suffers from relative southerly isolation, San Diego reaps immense benefits from its proximity to Los Angeles and Orange County to the North, and Phoenix to the East. In fact, San Diego now acts as a secondary hub for traffic between Los Angeles and Phoenix on a variety of networks including; AGIS, AT&T, CAIS, Electric Lightwave, Epoch, and others.

3.3.2 Metropolitan Area Accessibility

Although analysis at the citywide level provides interesting results, analysis of POPs aggregated to Metropolitan Statistical Areas and Consolidated Metropolitan Statistical Areas also provides a solid geographical framework for metropolitan rankings and comparisons. As mentioned previously, an increasing prevalence of metropolitan fiber rings interconnecting larger metropolitan areas means that POP clusters are not neatly tied to city boundaries. For example, an analysis of San Jose alone fails to incorporate the more meaningful context of San Jose and its location in Silicon Valley. Therefore, the remainder of this section will provide an analysis of POP presence and metropolitan area accessibility for the US.

Figure 3.5 illustrates a three-panel map of MSAs/CMSAs and the presence of POPs for 1997, 1999, and 2000. Although many of the same general patterns are evident with data aggregation, there are some notable differences between the city-wide analysis and the MSA/CMSA analysis. The 1997 panel more clearly illustrates the domination of the Washington DC-Baltimore (n = 44) and San Francisco-Oakland-San Jose (n = 55) CMSAs in POP presence. Much of this early dominance can be attributed to the presence of network access points that interconnect large volumes of both national and international traffic. Moreover, network analysis performed by Wheeler and O'Kelly (1999) confirms that Washington DC was the most accessible city on the commercial Internet in 1997.

Recall that the analysis forwarded by Wheeler and O'Kelly (1999) did not use aggregate measures at the MSA level. However, the cities of San Jose, San Francisco, Palo Alto, and Santa Clara were all ranked in the top 30 cities for accessibility.
Figure 3.5: POP Counts by MSA/CMSA

POP Counts
- 0
- 1 - 5
- 6 - 10
- 11 - 20
- 21 - 30
- 31 - 40
- 41 - 60
- 61 - 88
The 1999 panel illustrates more significant changes in the POP landscape. The Washington DC-Baltimore CMSA remains the second highest ranked metropolitan area in terms of POP presence for 1999 with Chicago being a close third. However, if one recalls the city-wide comparisons in 1999, San Jose was not included in the top ten cities. In fact, it ranked at 12th, with a total of 23 POPs and was identified as an "emerging" center for POP presence in the Section 3.3.1. However, this city-wide ranking approach tends to underestimate major telecommunication clusters in areas like Silicon Valley. If we were to simply evaluate the new aggregated total for the San Jose MSA, 48 commercial backbone points of presence in the area. Extending the aggregation to include the San Francisco-Oakland-San Jose CMSA reveals a total of 84 POPs as illustrated in Figure 3.5. This is a very significant shift in the overall picture of metropolitan accessibility. Other patterns worth noting include the emergence of regional centers for POP presence. This includes metropolitan areas such as Denver, Salt Lake City, Kansas City, St. Louis, Columbus, Las Vegas, and Portland. Although these metropolitan areas are not within the top tier of POP clusters, they are emerging regional aggregation points for backbone providers, displaying higher levels of market demand for telecommunication services in 1999 (Moss and Townsend 2000; Townsend 2001).

The panel for 2000 (Figure 3.5) also displays some remarkable patterns. One major trend continues; metropolitan areas with the presence of an NAP or MAE (or a combination of both) remain dominant. The Washington DC-Baltimore, San Francisco-Oakland-San Jose, Chicago, New York and Los Angeles CMSAs continue to exhibit numerous POPs. Again, if we focus on the Washington DC-Baltimore CMSA, significant empirical proof exists to support its high ranking. The Route 267 corridor, stretching from DC to the Dulles airport in Virginia is home to a many Internet, telecommunication, and optical networking companies, including; WorldCom, Nextel, AOL, Teligent, PSINet, and Ciena (Serwer 2000). In fact, Serwer (2000) notes that the Washington DC metro area now has more people working at information technology companies than in the government. Given the burgeoning market demand in this area combined with the Washington DC NAP, and MAE East in Vienna, VA, it is no surprise that this CMSA is ranked so
highly. Additional interesting comparisons can be made between metropolitan areas. For example, there is a dramatic difference between the number of POPs located in Dallas-Fort Worth (48) versus a more trumpeted center of innovation of Austin-San Marcos (19). The Austin area is figuratively known as the “Silicon Hills”. Home to Dell Computer, Austin’s technological focus is on computer and chip manufacturing along with software design (Ladendorf 2000). In contrast, Richardson, Texas, a booming suburb of Dallas, is home to numerous telecommunication giants including WorldCom, Fujitsu, Nortel, Alcatel, and Samsung. Clearly, the technological focus of Richardson is on the hardware and software to control high-speed fiber optic networks. Therefore, the combination of a Tier 1 MAE in Dallas and the massive agglomeration of telecommunication companies in Richardson creates a very attractive environment for backbone operators to locate POPs.

Figures 3.6 and 3.7, which display several derived measures of POP presence and its relationship to other indicators of the digital economy, further support the patterns evident in Figure 3.5 for the year 2000. Figure 3.6a is the Pearson’s correlation matrix for these indicators. As expected, population, bandwidth, and domain registrations (all surrogates for market demand) display significant and positive correlations with points of presence. In addition, the number of utility patents issued by the U.S. Patent and Trademark Office displays significant and positive correlations to all three indicators of market demand. As Cortright and Mayer (2001) suggest, patent registrations provide a rough measure of the innovative activity in a metropolitan area, which is frequently indicative of high technology centers such as Boston, Austin, and Portland. Perhaps the most intuitive result is the relationship between bandwidth and POPs. As mentioned previously, POPs are the principle way to “tap” into fiber optic bandwidth on a telecommunication network. Figure 3.6b illustrates the relationship between bandwidth availability and POPs for a select group of MSA/CMSAs. Miami has the smallest amount of bandwidth available per POP. Miami’s geographic isolation from the core transcontinental backbones is surely a significant

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8 90% of all patents issued within recent years have been utility patents, also referred to as “patents for invention” (PTO 2001).
## Correlations

<table>
<thead>
<tr>
<th></th>
<th>POPULATION</th>
<th>DOMAINS</th>
<th>BANDWIDTH</th>
<th>U_PATENTS</th>
<th>POPS</th>
</tr>
</thead>
<tbody>
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<td>Sig. (2-tailed)</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DOMAINS</strong></td>
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<td>.000</td>
<td>20</td>
<td></td>
</tr>
<tr>
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<td>.675**</td>
<td>.001</td>
<td>.001</td>
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<tr>
<td><strong>U_PATENTS</strong></td>
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<td>.696**</td>
<td>.819**</td>
<td>.606**</td>
<td>.001</td>
</tr>
<tr>
<td><strong>POPS</strong></td>
<td>Pearson Correlation</td>
<td>.705**</td>
<td>.822**</td>
<td>.863**</td>
<td>.779**</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 3.6: A: Pearson Correlation Matrix
B: Bandwidth (mbps) by Point of Presence
Figure 3.7: A: Domains (1000s) by Point of Presence
B: Domains (1000s) by Point of Presence
In addition, four of the top six cities (Washington, New York, Dallas, Chicago) in Figure 3.6b host a major interconnection point (NAP/MAE), while the remaining two (Denver and Atlanta) serve as the most important interconnection locations for their given regions. Figure 3.7a displays a simple comparison between POPs and population for a select group of metropolitan areas. These data suggest smaller metropolitan areas such as Austin, and Portland, both with strong local economies rooted in technology, have more POPs than one might expect if evaluating strictly by population. Finally, Figure 3.7b displays the number of domain names registered for each POP in the same set of metropolitan areas. Due to the sheer number of domains registered in Los Angeles and New York, these cities exhibit a relatively high imbalance between domains and POPs.

3.3.3 Emerging Centers of Internet Presence and Accessibility

Given the massive growth in POPs across the United States since 1997, documenting metropolitan areas displaying the most significant growth is worthwhile. Not only will the results of this process provide a basic indicator of infrastructure development, deployment, and access, the results will also serve as moderate indicators of economic expansion and growth for these metropolitan areas (Zook 2000a; Glasner 2000).

Figure 3.8 illustrates the relative change in POP presence for metropolitan statistical areas between the years of 1997 and 2000. This figure highlights the five MSAs displaying the largest increase in POPs during this period. For example, the Portland-Vancouver CMSA experienced a 13.5-fold increase in POPs between 1997 (2 total) and 2000 (29 total). It is interesting to note that the city of Portland currently ranks 17th among all US cities for domain registrations, while the state of Oregon ranks 20th in the US for domain registrations (Network Solutions 2000). Further, the communities of Beaverton, Aloha, and Hillsboro (all within the Portland-Vancouver CMSA) host the largest Intel campus in the world. In fact, Beaverton and Hillsboro are home to the Intel staff involved with the Internet, networking, communications, and server products, as well as the Intel Architecture Laboratories (Intel, 2000). Portland also enjoys
Figure 3.8: Relative Change - 1997 - 2000 by MSA/CMSA
the locational advantage of being an intermediate stop between the San Francisco/San Jose and Seattle CMSAs. Therefore, Portland’s growing market demand for bandwidth, local economic base, and an enviable location provide some empirical proof to the rapid growth of POPs in this CMSA.

The growth of POPs in the Tucson MSA is another interesting trend. Tucson has a well-deserved reputation for being a major research center for optical technologies. In fact, the University of Arizona produces more graduates in optical science than any other institution in the United States (Futurewest 2000). Given the rising importance of optical networking, Tucson certainly represents an area of increasing importance for the commercial backbone industry. That aside, one might suggest that Tucson’s geographic location is also spurring POP growth. Located a mere 100 miles from Phoenix along Interstate 10, Tucson benefits from Phoenix’s role as a major telecommunication gateway to the Southwest. Twenty-five backbone providers have a POP in the Phoenix-Mesa MSA. Therefore, given the presence of the University of Arizona, an important research cluster in optics and teleservices, and nearly 920 miles of fiber optic cable in Tucson, the nine-fold increase in POPs between 1997 and 2000 is not that surprising.

Figure 3.8 illustrates a ten-fold increase in POPs for the Milwaukee MSA between 1997 and 2000. Again, as the backbone industry continued its rapid expansion over the last four years, cities like Milwaukee greatly benefited from their proximity to major telecommunication centers such as Chicago. In fact, only 100 miles separate these two urban centers. Therefore, expansion to a fairly large market such as Milwaukee (1.4 million) along Interstate 94 makes good strategic sense for backbone operators.

The Nashville-Davidson MSA also witnessed a ten-fold increase in POPs over the past four years. Nashville benefits from a very extensive local telecommunication infrastructure. For example, there are over 144,000 miles of fiber optic cable in the region. More importantly, BellSouth has the capabilities to install fiber distributed data interfaces in its local central offices/wire-centers, the same equipment required for interconnection in Tier 1 MAEs (BellSouth 2000).
Finally, the New Haven-Bridgeport-Stamford MSA displayed the most dramatic increase in POPs between 1997 and 2000. It should be noted that this MSA is located within the New York CMSA. Therefore, one might assume that the thirteen-fold increase in POPs is due to its proximity to New York City and the I-95 corridor. To a certain degree, this is true. The New York CMSA experienced a 120% growth rate in POPs between 1997 and 2000. A fair portion of this can be attributed to the POP growth in the New Haven area. The New Haven MSA also represents an intermediate point between New York and Boston. Therefore, the opportunity for regional service and interconnection to the residential and business markets in the New Haven-Bridgeport-Stamford MSA (1.6 million pop.) is certainly a beneficial one for network providers. Interestingly, Stamford, Connecticut is also home to Citizens Communication (CC). CC is a fast growing telecommunication company that provides service to over 1 million customers nationwide. Further, CC owns 86% of Electric Lightwave, a broadband communication company that operates high-speed fiber optic networks in the United States and operates a leading national Internet and data network for transit (Citizens Communication, 2000; Boardwatch, 2000). One final piece of empirical evidence worth mentioning is that of domain growth in this MSA. Network Solutions projects that the New Haven-Bridgeport-Stamford MSA will rank in the top 10 MSAs for domain registrations by January of 2001. Although not directly tied to the presence of POPs, rapid increases in domain registrations certainly suggest an increasing presence of Internet based activity and market demand for bandwidth (Zook 2000; Moss and Townsend 2000; Gorman 2001).

3.4 Discussion

It is clear that the market for interconnection and access at the national level is changing rapidly. In only four years, the approximate number of POPs in the United States has increased 200%. The empirical results presented in this chapter also illustrate that the spread of POPs at the city-wide and MSA/CMSA level is geographically uneven. This disparity in POP presence has serious implications for access to the commercial Internet. As mentioned earlier, POPs often
represent the only means of connecting to a national commercial backbone. Therefore, if POPs are absent from metropolitan areas, access choices are limited, network performance can be subpar, and the economic development afforded by a strong telecommunication infrastructure is jeopardized.

There are several additional points illustrated in this chapter. First, the most recent wave of POP growth has occurred in metropolitan areas that share many similar spatial characteristics. Tucson and Milwaukee are both within 100 miles of major telecommunication centers (Phoenix and Chicago respectively). These major centers act as telecommunication gateways to their respective regions and beyond. In the case of Chicago, a major NAP and MAE are present acting as collection points for national traffic and collection points for regional traffic destined to Minneapolis, Milwaukee, Indianapolis, Columbus, and Cleveland. Phoenix shares a similar role, acting as a gateway for traffic originating in the southwest and destined to metropolitan areas such as Los Angeles, Las Vegas, El Paso, and Albuquerque. Therefore, Tucson and Milwaukee directly benefit from these large telecommunication clusters in neighboring metropolitan regions because of their spatial proximity. National backbone providers embrace these market opportunities in adjacent metropolitan areas where they have decided to locate additional POPs.

Second, metropolitan areas such as Portland and New Haven also benefit from regional geography. Both of these MSAs enjoy the benefits of being convenient intermediary points between two larger CMSAs with extremely high levels of Internet activity and presence. In the case of Portland, Seattle and San Francisco/San Jose are the two larger metropolitan areas. In the case of New Haven, New York/Boston are the two larger CMSAs. As mentioned earlier, fiber optic cable often follows existing transportation paths such as railway beds and Interstate corridors (Moss and Townsend 2000). Therefore, Portland represents a CMSA with the combination of strong market demand (the presence of Intel’s largest corporate campus and a tech-literate populous) and a convenient/strategic location (along Interstate 5). New Haven also represents the combination of a convenient location (along Interstate 95) and a good market demand (domain growth and tech-literate populous).
Third, Nashville is a good example of a rapidly growing MSA with a strong telecommunication infrastructure and centralized location. In a sense, Nashville is difficult to ignore for the larger backbone providers. One million residents generate a fairly high level of market demand for backbone services. Nashville is also home to a large portion of the country music entertainment industry; an industry that clearly embraces the benefits of marketing and sales on the Internet. Further, Nashville is also the state capitol of Tennessee, so a certain amount of demand is directly generated from government functions.

Fourth, the local economic characteristics of a region impact the amount of telecommunication investment. The market demand for bandwidth fueled by e-business, software development, telecommunication firms, government, and other industries is clearly demonstrated by the empirical evidence presented in the previous section. In addition, Figures 3.6 and 3.7 illustrate the relationships between innovative activity (utility patents), domain name registrations, bandwidth, population, and telecommunication investment.

3.4.1 Analytical Issues

The use of POPs for the analysis of city accessibility to the commercial Internet does pose some problems. As mentioned previously, the data set utilized in this study is somewhat simplistic. POPs documented in the Boardwatch Directory of Internet Service Providers do not necessarily reflect the true distribution of POPs for each backbone provider. The market for Internet access and interconnection is changing rapidly and only the network providers have current lists of POP locations. However, the use of Boardwatch does allow for a standardized longitudinal analysis of the POPs that are documented.

More problematic is the lack on knowledge of interconnection agreements and peering that takes place at POPs within the NAPs, MAEs and IXs. Access quality and options for metropolitan areas really hinge on these agreements. As mentioned earlier, the presence of a POP does not guarantee good service. All backbones are not created equal; so an understanding of which companies have peering agreements and the locations that they are
peering would provide a stronger empirical basis for analysis. Further, although POP locations listed simply as cities provides a decent spatial basis for investigation, the actual mechanics of interconnection occur at a more resolute scale. Although there are fiber loops located in most metropolitan areas, routers for interconnection are located in buildings. So, if a router for Company A is located in telecom hotel 1, and a router for Company B is located in telecom hotel 2, interconnection becomes more difficult. Unless these telecom hotels are sharing fiber of some kind, peering cannot take place.

Finally, this chapter has empirically illustrated issues surrounding spatial clustering of telecommunication entities and the geographical context in which this process is taking place. Again, it is worthwhile to revisit the city of San Jose for illustration. Taken out of the context of Silicon Valley, San Jose's relative ranking was not very high in terms of POP presence during 2000. When the surrounding communities in Silicon Valley are incorporated into the San Francisco-Oakland-San Jose CMSA, along with the POPs for this region, significant shifts in the telecommunicative hierarchy occur. In fact, the San Francisco-Oakland-San Jose CMSA is ranked 1st overall in 2000. Clearly, the need for defining the appropriate areal unit for spatial analysis, as discussed in Openshaw and Taylor (1981) is important in telecommunication research.

3.5 Summary

This chapter provides an empirical investigation of city accessibility to the commercial Internet utilizing a longitudinal data set of backbone provider points of presence for the United States. Results indicate that city accessibility, both in terms of number of options and quality of connections, is likely affected by the uneven geographic diffusion of POPs. The spatial disparities in the distribution of POPs are indicative of several factors. First, the telecommunication industry during the latter half of the 1990s was one of the most competitive sectors in the domestic economy, leading to a flurry of bankruptcies, mergers, and consolidations (Tally, 2000; Gorman and Malecki, 2000). Because of an increasing emphasis on profit in this
competitive market, telecommunication companies continue to extend their reach only to the urban markets they deem most profitable (Caristi, 2000; Gorman and Malecki, 2000). This means that many of the more remote or rural areas remain without adequate infrastructure. As such, the emerging hierarchy between global, national, and regional cities with their varying levels of telecom infrastructure continues to develop (Townsend, 2001). It is likely that this hierarchy will continue to shift, both categorically and geographically in the future. Continued infrastructure investment in cities like Miami suggest an increasing importance of global gateways to emerging telecommunication markets such as Latin America (Garcia, 2000).
As illustrated in Chapter 3, the business of interconnection in the US commercial backbone industry is a growing one. With the number of commercial POPs increasing over 200% between 1997 and 2000, certain cities exhibit more interconnection options than ever. Although the locations of POPs and data-centers provide good measures of city accessibility to the commercial Internet, there are additional pieces of the puzzle. Perhaps the most important aspect of city accessibility is measured by the actual backbone connections between cities (Wheeler and O’Kelly, 1999). These connections represent the pathways that data packets traverse from an origin node (city) to a destination node (city).

With the rising popularity of the Internet it is not surprising that the commercial backbone infrastructure of the United States is also experiencing a period of unprecedented growth. For example, in just two years (1997 – 1999) the total backbone capacity of the United States grew 420% (Moss and Townsend, 2000).

Similar to the spatial trends identified in Chapter 3, this growth is not distributed uniformly across space. As previous research suggests, the spatial organization of US commercial Internet backbones reflects an increasingly competitive, profit-motivated market (Gorman and Malecki, 2000). As a result, large urban centers with larger levels of market demand frequently benefit from infrastructure upgrades that increase capacity and extend the geographic reach of backbone
networks. The resulting agglomerations of high-capacity links make these metropolitan areas more accessible than others (Wheeler and O’Kelly, 1999; Moss and Townsend; 2000; Gorman and Malecki, 2000). At the same time, many of the more rural or isolated locations in the United States are not benefiting from frequent infrastructure upgrades. For example, Chicago is served by multiple OC-48 (2.488 Gbps) fiber trunks from a single Internet service provider. This type of capacity reflects a central location, high market demand, and the presence of a network access point (NAP) and a metropolitan area exchange (MAE).

Conversely, although a city such as Minneapolis to be served by an OC-48 connection, Minneapolis is not served by multiple OC-48 connections from any single provider. This lack of infrastructure reflects decreased market demand (relative to Chicago) and the relative isolation of Minneapolis to the US commercial Internet. Rather than being a hub of Internet activity like Chicago, Minneapolis can be classified as a very large spoke.

The type of disparity illustrated between Chicago and Minneapolis is magnified as one moves down the hierarchy of cities in the United States. For example, cities like Mobile, (Alabama), Fargo, (North Dakota), and North Platte, (Nebraska) represent much smaller markets, which are less likely to be served by high-capacity backbone links. Previous research indicates that the relative location of cities plays a major role in determining the level of service and accessibility to backbone connections. For example, Wheeler and O’Kelly (1999) suggest that cities like Miami and San Diego suffer from the “end of track” phenomenon, where backbone accessibility is much lower due to the geographic isolation of these cities. However, as they open gateway connections to the rest of the world (especially Latin America), their role as portals is increasing.

Given the rapid changes in the commercial backbone industry over the past few years, it is worth exploring the ways in which increased competition, network consolidation, and infrastructure investment manifest in a spatial context. Are cities like Miami and San Diego still

\[\text{Atlanta, Chicago, Los Angeles, New York, San Francisco Dallas and Washington DC are consistently identified as the most well connected cities.}\]
relatively isolated? Has the commercial Internet reconfigured its topological structure to provide better accessibility in smaller markets? Can cities make major strides in accessibility through new network configuration? Although Chapter 3 indicates an increase in POPs for cities such as Miami and San Diego, is there evidence of network growth in conjunction with these hardware upgrades? It is clear that recent changes in the backbone industry, including the recent period of expansion, make previous research efforts documenting city accessibility and network connectivity outdated. With that in mind, the purpose of this chapter is to provide a more current snapshot of city accessibility to the commercial Internet in the United States. Special attention will be paid to the economic changes induced by telecommunication infrastructure in metropolitan areas. Further, this chapter will attempt to forward a standardized methodology for examining city accessibility to the commercial Internet.

The remainder of this chapter is divided as follows. Section 4.2 presents a general overview of telecommunication networks, their structure, and their purported role in the economic development of urban centers. This is followed by pertinent background information on the evolving commercial backbone industry in the United States, where emphasis is placed on the continuing trends of mergers and consolidations. Section 4.3 presents details regarding the empirical database used for analysis and the structure of the application study. Results will then be presented (Section 4.4) followed by a summary and conclusion in Section 4.5.

4.1 Telecommunication Networks

There are a wide variety of telecommunication networks, each serving a different purpose and taking a different form. At the most basic level, networks are classified as either “switched” or “non-switched”. Non-switched systems are typically broadcast networks that transmit only one type of information from a single location to a large number of listeners (Newton, 2000). For example, television broadcast networks are non-switched systems. In contrast, switched telecommunication systems provide a variety of services (voice, data, and video) through a
shared network system. As one might expect, the Internet represents the largest switched telecommunication network in the world.

Although the technical differences between switched and non-switched networks are fairly clear, the network characteristics defining the Internet are infinitely more complex. In order to make accurate assessments of city accessibility to such a network, one must address the technical foundations and topological characteristics of switched systems.

4.1.1 Network Primers

There are several important aspects of switched telecommunication networks that must be addressed; these include switching techniques, network typologies, and network topologies, and network reliability. All four components can influence city accessibility to the commercial Internet.

First and foremost, the Internet is a packet-switched network. Packet switching permits the transfer of information between two subscribers through the routing of addressed packets of user data through the network (Sharma, 1990). As Newton (2000) notes, because packets are independent from each other (each contains a unique ID) packets may follow different physical pathways of varying lengths to reach their destination. For example, one set of data packets originating in Columbus and destined for Chicago might flow directly between the two cities over a single path. However, portions of the same data transmission might also utilize a two-step path. Instead of flowing directly from Columbus to Chicago, some packets may flow from Columbus, to Cleveland, to Chicago. This is one of the primary sources of “latency”. Latency refers to the various aspects of time delay for network communications (see for example, Murnion and Healey, 1998). In direct contrast to packet-switched networks are circuit switched networks. These provide a private, hardwired connection through a network between two subscribers (Sharma, 1990). The public switched telephone network (PSTN) is a good example of a circuit switched network.
In addition to the switching technologies employed on networks, one must also consider the actual type of network in use. Sharma (1990) and Newton (2000) outline the spatial characteristics of three different networks. Local Area Networks (LANs) are the smallest in geographic coverage. LANs typically connect personal computers, workstations, or printers in a single building or across multiple buildings on a campus. The most popular type of LAN is Ethernet, which operates over twisted wire and coaxial cable with speeds approaching 10 Mbps. Metropolitan Area Networks (MANs) are high-speed intra-city networks that link multiple locations. MANs cover areas of about 50 miles and provide speeds up to 200 Mbps. Lastly, Wide Area Networks (WANs) are very high-speed networks that cover distances of approximately 500 miles.

Where the commercial Internet is concerned, “backbones” represent combinations of LANs, MANs, and WANs that carry large amounts of traffic over long distances. For example, Figure 4.1 illustrates the now defunct GetNet backbone for 1997. Given the spatial configuration of the GetNet backbone, several conclusions can be made. First, it is likely that GetNet peered with other backbones at the Santa Clara CIX and the Washington DC NAP. In 1997, these locations represented two of the most active peering locations in the U.S. for all backbones (Rickard, 1999). Second, one might also suggest that the GetNet backbone was connected to the MANs in all five cities where service was provided. As illustrated in previous research (Gorman and Malecki, 2000), these types of connections are very common in the backbone industry. Third, although the number of cities served by GetNet in 1997 is small, the geographic service area is relatively large (transcontinental).

Network topology and its role in telecommunication access is also an important consideration. In general, topology defines the manner in which network nodes (cities) are interconnected. There are many different topological frameworks that are utilized in telecommunication systems. Figure 4.2 illustrates several of the most basic system topologies, including Mesh, Ring, Star, and Hub and Spoke. As Figure 4.2 demonstrates, a partially connected mesh topology allows for a direct link between certain pairs of nodes in a network.
Figure 4.2: Common Backbone Topologies
From an economic perspective, the partially connected mesh is advisable when traffic flow between certain nodes is low. The interaction between low-flow nodes can be switched to longer paths resulting in a better economy of scale (Sharma, 1990). The Star topology utilizes a single switching node that directly connects subscribers. This type of topology is frequently used on campus networks in order to connect all subscribers to a PABX voice or data switch\textsuperscript{11}. Hub and Spoke network topology is designed for serving information flows between multiple origins and destinations. As O'Kelly and Miller (1994) note, hubs allow for the construction of a network where direct connections between all origins and destinations (fully connected mesh) is replaced with fewer indirect connections. This reduces construction costs and allows for scale economies through the consolidation of flows (O’Kelly and Miller, 1994). Considering that the cost of transmission in most telecommunication networks is predominately influenced by link costs versus switching, the hub and spoke system for telecommunication can make good sense if capital is restricted.

The final piece of the network puzzle deals with reliability. As Liu et al. (2000) note, reliability theory is concerned with estimating the probability that networks (systems modeled as graphs) are functional given the failure probability of their elements. Where networks are concerned, this measures the probability of links (backbones) and nodes (switches) remaining operational at any given time. To minimize the probability of failure and service disruption, Bateman (1997) outlines several strategies available to transit level Internet service providers.

1. \textit{Mesh-routing strategy} – the provision of alternate routes between nodes, even if traffic levels do not justify additional plant.

2. \textit{Network redundancy} – a suitable overprovision of transmission and switching capacity are added in advance of additional capacity being warranted by forecast traffic growth.

\textsuperscript{11} PABX stands for “Private Automatic Branch Exchange.” Today, the are usually referred to as “PBXs” and are automatic. This means that an operator is no longer needed to place a call (Newton, 2000).
3. **Service-protection network** – Provides reserve capacity extending over the major links of the transmission-bearer network.

4. **Transmission-routing diversity** – Minimizing the vulnerability of large traffic routes (e.g. New York to Chicago) by spreading traffic between nodes over two or more separate transmission paths.

5. **Automatic alternative routing** – Ability to circumvent congestion or failed links within the network.

Recently, network reliability and survivability were tested when a train carrying hazardous materials derailed in a tunnel outside of Baltimore, Maryland. Because fiber-optic backbones from major providers such as WorldCom, PSINet, and AboveNet were also located in the tunnel, major Internet slowdowns, which began in the Middle Atlantic States, rippled across the country as companies diverted Web traffic to other links (AP, 2001a).

### 4.1.2 Backbone Topology and Economics

When examining backbone topology at the national level, it is important to retain a focus on the evolution of the Internet. Many of the geographic characteristics of the Internet at the national scale are directly related to the “corporate” evolution of the Internet and its economics during 1990s. As noted in Chapter 2, the current geography of the commercial Internet backbone is far from the distributed topological structure originally planned.

The primary impetus for locating Internet backbones is based in economics, not geography. Backbone links are constructed to serve market demand for bandwidth. Therefore, the location of backbone links often reflects the demand between city pairs. For example, one of the most common commercial backbone links found in the United States exists between the cities of Chicago and New York. As two of the largest cities in the United States, both Chicago and New York are centers of industry and commerce and have very high levels of interaction between each other. Moreover, both cities contain public NAPs. The market economics of a city pair like
Chicago and New York is relatively simple; higher levels of interaction spur the construction of higher capacity backbones between the two cities. Network providers often construct redundant direct links between city pairs to eliminate bottlenecks at less important, intermediate locations (Moss and Townsend, 2000). For example, WorldCom currently maintains two different 10 Gbps backbone links between Chicago and New York (WorldCom, 2001). Given these market conditions, it is very likely that the interaction between Chicago and New York (42,480 Mbps of backbone capacity) will significantly outweigh the interaction between a smaller market pair such as Milwaukee and Minneapolis (7643 Mbps of backbone capacity). As a result, the amount of bandwidth available in a direct connection between Milwaukee and Minneapolis (if it exists) is substantially reduced.

If market demand is controlled for, the geographic manifestations of backbone links between cities pairs become rooted in the practicalities of network engineering and construction. As Moss and Townsend (2000) note, Internet backbones typically “traverse private and public rights-of-way, often alongside highways or railroad lines, to connect metropolitan areas across the country”. From an engineering perspective, these locations often represent the best possible path between two cities, with highways serving as direct connections between cities and their medians providing ample space to bury fiber optic lines (Gerwig, 2001; Mohney, 2001).

Examples of the interaction between market economics and geography are illustrated in Figure 4.3, which displays the GST Communications network in the western United States. There is a striking similarity between the location of its fiber optic cables and the Interstate highway system. For example, the Portland, Oregon and Seattle, Washington connection runs directly adjacent to the Interstate 5 corridor. In addition, the Albuquerque, New Mexico and Dallas, Texas connection utilizes significant portions of the Interstate 25 and Interstate 20 corridors.
Figure 4.3: GST Communication Network – 1999
Source: http://www.gst.com
4.1.3 Access

The topological similarities between Internet backbones and transportation infrastructure are well documented (Wheeler and O’Kelly 1999; Gorman and Malecki, 2000). In addition to Internet backbones sharing similar physical pathways with the U.S. transportation network (Moss and Townsend, 2000; Mohney, 2001; Gerwig, 2001), the role of cities as “nodes” remains important.

At the most basic level, access hinges on network presence. In other words, a city must be located on the network. The position of a city on the network, relative to other cities and existing network linkages, is the primary way to evaluate accessibility. Because backbone providers maintain a point of presence (POP) in most major cities, these locations become analogous to nodes in a transportation network. As illustrated in Chapter 3, POPs act as “on-ramps” to the commercial Internet backbone system, linking Internet users worldwide.

For those locations with the appropriate infrastructure, relative accessibility to other locations on the network continues to be a key element. As Moss and Townsend (2000) convincingly argue, the Internet backbone system represents the newest form of urban infrastructure. Similar to the transportation networks of the past two centuries (rail, road, air, water), the Internet transports the “valuable goods” of the digital economy – information, knowledge, and communication (Moss and Townsend, 2000). Cities represent the locations where these goods are both produced and consumed (Kellerman, 2000; Zook, 2001). Therefore, as the digital economy continues to evolve, the relationship between producers, consumers, and the Internet becomes more important. (For a more thorough review of the existing work on backbone topology and access, see Chapter 2.)

Where network accessibility and performance are concerned, a few milliseconds difference may not be noticed by an individual end-user; however, the aggregate impact of millions of messages saving network hops, or experiencing lower latency may well give significant locational advantage to places with high accessibility. For example, it is fairly well understood that the nucleus of the global Internet is the United States (Cukier, 1999, Gorman and Malecki,
2000; Townsend, 2001). With extensive fiber optic infrastructure, massive agglomerations of metropolitan bandwidth, and numerous public and private peering points, network performance within the United States is significantly better than most locations in the world (Gorman and Malecki, 2000; Townsend, 2001). As such, e-businesses in Europe frequently pay U.S. Internet service providers for both web-hosting and transit in order to reach European users. For example, Cukier (1999) notes an example where FranceNet SA began operating a large server center in California and leasing space from the U.S. based Internet service provider, GlobalCenter. Not only does the relative network location of major cities in California (e.g. San Francisco, Los Angeles) boost performance, the costs associated with leasing bandwidth in the United States are significantly lower than Europe (Cukier, 1999; Galbi, 2001).

It is important to note that these issues of performance, quality of service, and network accessibility are not simply a difference between the U.S. and the rest of the world. A wide variety of techniques are currently employed to minimize the amount of Internet latency end-users experience in the United States. As Pollack (1999) notes, a web-page distribution system utilized by NBC and Intuit places material on strategically located web-servers (mirror sites) to speed the delivery of information to the end user. Although the actual locations are not divulged, it is a safe bet that these mirror sites are located in metropolitan areas with better-than-average network accessibility. It is within such contexts that relative network location and city/nodal accessibility remain an important issue to the growing digital economy.

4.2 The Commercial Backbone Industry

In the most recent issue of Boardwatch’s Directory of Internet Service Providers, over 40 competing networks are listed which provide long-haul backbone services in the United States. According to the Cahners In-Stat Group (2001), revenues for the backbone connection market will have a compound annual growth rate of 16.82 percent between 1999 and 2004. In addition, Cahners estimates a 23% growth rate in backbone connections during the same time frame (Robuck, 2001).
Given the rapid growth in this sector, it is interesting to note that the major players in this industry are also undergoing significant change. For example, Wheeler and O'Kelly (1999) analyzed 31 different backbone providers for the year 1997. As Table 4.1 illustrates, by the year 2000, only 4 of the 31 networks analyzed in that study were unchanged. The other 27 networks underwent consolidation, merged with another backbone company, or filed for bankruptcy. These results clearly suggest the commercial backbone industry is in a state of flux. Sections 4.2.1 and 4.2.3 highlight several important developments in the backbone industry between 1997 and 2000.

4.2.1 Telecommunication Mergers

MCI/WorldCom/UUNET

Perhaps the most significant merger over the past three years occurred in 1998 with WorldCom and MCI. MCI was one of the largest long-distance service providers in the U.S., while WorldCom was one of the largest players in the commercial backbone industry. Under intense scrutiny from the U.S. Department of Justice (DOJ), MCI was forced to sell their Internet backbone services in order for the merger to be accepted. In this case, Cable and Wireless purchased the MCI backbone for $625 million. Although this was a major loss in infrastructure, WorldCom was still able to maintain a strong position in the U.S. backbone business. Two years earlier (1996), MCI had acquired MFS, owners of the large UUNet backbone network and in 1998 WorldCom acquired the CompuServe backbone. Today, the UUNet based WorldCom backbone contains 221 active switching facilities and hubs with thousands of miles of high capacity fiber cable connecting cities in the US and abroad (Boardwatch, 2000). In fact, the WorldCom network currently maintains a 37% market share for wholesale backbone traffic in the United States (Borland, 2000).

Of great interest is the fact that in October of 1999 WorldCom and Sprint proposed the largest telecommunications merger in history. WorldCom, the second largest long-distance company in the United States tendered an offer of $115 billion to acquire Sprint, the third largest long-distance company in the US. The U.S. Department of Justice blocked the proposed merger
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<tr>
<td>AGIS</td>
<td>Bankrupt - Remnants sold to Telia AB</td>
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<tr>
<td>ANS</td>
<td>Bankrupt - Remnants sold to UUNET</td>
</tr>
<tr>
<td>AT&amp;T</td>
<td>Acquired - CERFnet, IBM Global Network, TCI.</td>
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<td>ATMnet</td>
<td>Acquired by Verio</td>
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<td>BBN Planet</td>
<td>Acquired by GTE/Verizon</td>
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<td>CertNet</td>
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<td>CompuServe Network</td>
<td>Network acquired by WorldCom</td>
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<td>CRL Network Services</td>
<td>Acquired by Applied Theory</td>
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<td>Dataexchange Network</td>
<td>Acquired by RMI</td>
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<td>DIGEX Incorporated</td>
<td>Acquired by Intermedia</td>
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<td>EPOCH Networks</td>
<td>Largest privately held ISP in the United States **Still Active</td>
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<td>Genuity</td>
<td>Acquired BBN Planet Network</td>
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<td>GeoNet Communications</td>
<td>Acquired by Level 3 (OCT 1998) for $21 million</td>
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<td>GetNet International</td>
<td>Bankrupt - Acquired by Internet Access</td>
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<td>GlobalCenter</td>
<td>Acquired by Frontier Communications; merged with Exodus</td>
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<td>GoodNet</td>
<td>Acquired by WinStar</td>
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<td>GridNet International</td>
<td>Acquired by UUNET</td>
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<td>IBM Global Network</td>
<td>Acquired by AT&amp;T</td>
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<td>Icon</td>
<td>Acquired by Qwest</td>
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<td>IDT Corp</td>
<td>**Still Active</td>
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<tr>
<td>InternetMCI</td>
<td>Network acquired by Cable and Wireless</td>
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<td>iStar Internet Inc.</td>
<td>Acquired by PSINet</td>
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<td>Nap.Net, LLC</td>
<td>Acquired by GTE/Verizon</td>
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<td>Netrail Incorporated</td>
<td>**Still Active</td>
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<tr>
<td>PSINet</td>
<td>Acquired iStar Internet; **Still Active</td>
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<tr>
<td>Savvis Communications</td>
<td>Acquired by Bridge Information Systems - **Still Active</td>
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<tr>
<td>Sprint IP Services</td>
<td>**Still Active</td>
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<tr>
<td>UUNET/MFS/WorldCom</td>
<td>Merged with Sprint IP Services - Restructured as WorldCom (2000)</td>
</tr>
<tr>
<td>Verio</td>
<td>Acquired by NTT Communications</td>
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<td>VisiNet</td>
<td>Acquired by WinStar</td>
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<td>WebSecure</td>
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Table 4.1: Changes in the Internet Backbone Industry
citing violations of antitrust law. There were dozens of areas where the DOJ cited potential violations. For example, a company with the combined resources of WorldCom and Sprint would control 80% of the U.S. long-distance market, and 53% of the Internet backbone traffic (Borland, 2000).

**AT&T**

Not to be left out, AT&T is also busy staking its claim in the backbone industry. In addition to the 1998 acquisition CerfNet, AT&T purchased IBM’s Global Network backbone for $5 billion in 1999. Today, AT&T Global Network Services operates 53,000 route miles of fiber optic cable and 62 regional SONET rings in the U.S alone (Boardwatch, 2000). AT&T is making additional inroads at the local level through the acquisition of cable providers TCI and Media One. As a result, AT&T is the largest cable company in the United States.

**Qwest**

The last mega-merger worth mentioning is that of Qwest and US West. With an OC-192 capable nationwide network, the Qwest backbone contains 25,000 miles of fiber, connecting nearly 150 U.S. cities. In 2000, Qwest acquired US West, a Regional Bell Operating Company with service in 14 western states, with a $43.5 billion stock purchase. With this move, Qwest gained a local and long-distance customer base of nearly 25 million and over 40,000 miles of domestic infrastructure (Robuck, 2000). Qwest currently operates as the fourth largest long-distance company in the United States.

**4.2.2 Telecommunication Trends**

As the telecommunication industry continues to evolve, companies are constantly improving their array of services to maintain a competitive position. The evolution of telecommunication companies can take a variety of paths. As illustrated by MCI-WorldCom, mergers and buyouts are one way to strengthen a foothold in the industry. WorldCom is also indicative of a more general trend in the telecommunication industry that embraces a integrated
framework for telecommunication services. Instead of simply providing backbone services, companies are providing local and long-distance service, cable television, and residential broadband (digital subscriber lines, cable modems). This convergence of voice, video, and data represents the future for telecommunication companies. In fact, both WorldCom and AT&T, (among others) are now classified as competitive local exchange carriers (CLEC). CLECs compete on a selective basis for local exchange service, long distance, international, Internet access and entertainment by building their own local loops or leasing them from an incumbent local exchange carrier (Newton, 2000).

Given this trend, it is not surprising to find hybrid companies such as “Excite at Home” with their own backbone networks, providing both video and residential broadband services. However, as McCarthy (2000) points out, even with all the change spurred by increased competition in the access industry, the major players (WorldCom, Cable and Wireless, and Sprint) continue to dominate wholesale access to the Net.

One of the more interesting challenges to this wholesale dominance involves the concept of “bandwidth exchanges”. Broadly defined, a bandwidth exchange is a marketplace where telecommunication bandwidth is traded like a commodity; similar to energy or natural gas (Rieke, 2000). The basic argument for the utility of bandwidth exchanges is a simple one. Currently, it can take several weeks to negotiate bandwidth transactions and implement services. Whether this is bandwidth for long distance call minutes or point-to-point communications, the resulting contracts are often very rigid. For example, Company A needs access to a 622 Mbps connection for one year. Vendor B negotiates the price for this bandwidth and implements the service. Unfortunately, Company A underestimated its bandwidth needs by 400 Mbps. In order to increase bandwidth, Company A must renegotiate with Vendor B. More importantly, as backbone providers continue to upgrade infrastructure and increase bandwidth between U.S. cities, prices can fall between 10 to 15 percent a month (Rieke, 2000). Ironically, Company A may be locked into a higher priced contract for the initial 622 Mbps versus the secondary contract at 400 Mbps.
Given these types of problems, bandwidth exchanges attempt to circumvent long-term contracts by selling "blocks" of bandwidth on demand. For example, the Houston based energy company Enron, operates one of the larger bandwidth exchanges in the United States. If Company A needs an additional 400 Mbps; Enron is able to allocate the 400 Mbps through a series of "pooling points" where telecommunication providers maintain a presence (Enron, 2000). Contracts are not long term, they simply reflect the period of time where the bandwidth is needed. More importantly, with guarantees regarding the quality of service and delivery times, bandwidth exchanges like Enron allow companies to add bandwidth very quickly as their demand increases.

As Rieke (2000) notes, current estimates indicate that carriers can save between 25-50 percent by selling bandwidth as a commodity. More importantly, by selling bandwidth in this way, efficiency is greatly increased. Instead of having idle bandwidth between city pairs, backbone operators can sell excess capacity to the highest bidder. Current trends indicate that Enron is doing quite well with the bandwidth exchange concept. Utilizing bandwidth provided by Global Crossing between the cities of New York and Los Angeles, Enron completed more than 50 bandwidth exchange deals during 2000 (Rieke, 2000).

4.3 Network Analysis

The previous section highlights many of the pertinent issues surrounding the commercial backbone industry and city accessibility to the Internet. Although previous studies suggest major differences in accessibility exist between cities (Wheeler and O'Kelly, 1999), it is hypothesized that the rapid growth of the commercial Internet between 1997 and 2000 might reveal a shift in city accessibility rankings. This section, and the remainder of the chapter, proposes a standardized methodological approach for evaluating city accessibility to the commercial Internet and applies it to 1997 and 2000 data, both with a view to noting trends and comparing city rank.

Similar to transportation networks, the Internet can be reduced from its more complex spatial structure to one reflecting its most basic form. In this case, the transit backbones can be reduced to an array of nodes and links which form graphs. The topological evaluation of graphs
is known as *graph theory*. As Haggett and Chorley (1969) suggest, the treatment of networks as graphs carries a wide variety of benefits as well as penalties. Although one must incur significant losses of relevant information, higher levels of abstraction allow for the analysis of extremely complex graphs through the use of matrix algebra. Given the complexity of the Internet, this is a decided advantage.

Considering the utility of graph-theoretic measures, their application to telecommunication networks enjoys a long history (Nyusten and Dacey, 1961; Hakimi, 1964). One of the most basic applications of graph theory enables summary indices to be developed to compare networks. As illustrated in Table 4.2, Haggett and Chorley (1969) outline several useful measures for comparing networks.

**Cyclomatic Number** - The cyclomatic number is a basic indicator of network size, evaluating the number of edges, vertices and sub-graphs in a network. A sub-graph refers to non-connecting elements of the graph, where the nodes cannot be reached in a single cycle.

**Beta Index** - The beta index measures the complexity of a network. For example, because railroad and highway networks are planar (all intersections result in a node), they can never reach a beta index greater than 3. Considering that telecommunication networks are non-planar, locations where fiber optic cables cross do not necessarily form a new node. Therefore, as Gorman and Malecki (2000) note, the beta index of a non-planar graph can approach infinity.

**Alpha Index** - The alpha index is a ratio that measures the observed number of loops as a function of the maximum number of loops in a network (Haggett and Chorley, 1969). An *alpha* value of 1 (100%) indicates a fully meshed/connected network while a value of 0 indicates a branching network where the removal of any link results in the creation of sub-graphs. Gorman and Malecki (2000) suggest that the alpha value for the commercial Internet in 1998 was 51% -
A. Measures based on gross characteristics

Cyclomatic number = \( E - V + G \)

\( E = \) number of links (edges) in the network
\( V = \) number of nodes (vertices) in the network
\( G = \) number of sub-graphs

\[ \beta = \frac{E}{V} \]

\[ \alpha = \left( \frac{E - V + G}{V(V - 1)} \right) \times 100 \]

\[ \gamma = \left( \frac{2E}{V(V - 1)} \right) \times 100 \]

B. Measures based on shortest-path characteristics

Diameter = maximum \( D \)

\( d_{ij} = \) shortest paths (in links) between the \( i \)th and \( j \)th node

\[ \delta = \sum_{i=1}^{v} d_{ij} \]

\[ \rho = \sum_{i=1}^{v} \sum_{j=1}^{v} d_{ij} \]

Table 4.2: Elementary topological measures of Internet backbone structure
Source: Based on Haggett and Chorley (1969, p. 32)
which means that the Internet was not fully meshed and still had room to grow before network saturation was met.

**Gamma Index** – The gamma index indicates the number of alternate routes available in a network between nodes. As a measure of interconnection, gamma is also a good indicator of network provider strategy; with some ISPs opting for redundant links between city pairs and others pursuing more cost effective strategies such as hub-and-spoke configurations.

### 4.3.1 Backbone Data

Spatially, this analysis will focus on the 48 contiguous U.S. States. Network backbone information from the 12th Edition of the *Boardwatch Directory of Internet Service Providers* will be utilized for analysis (Boardwatch, 2000). These data are compiled annually by *Boardwatch Magazine*, the leading source of information on backbone providers, and Internet service providers in the United States. Similar data sets have been used extensively in previous research on the Internet (Wheeler and O'Kelly, 1999; Malecki and Gorman, 2000). As mentioned previously, the number of network providers included in the *Boardwatch* varies from year to year. Again, this reflects the numerous changes in the backbone provider industry. The 12th Edition contains information on 41 commercial backbone providers. Additional confirmatory data were acquired from the Cooperative Association for Internet Data Analysis (CAIDA) (based on the *Boardwatch data*) for comparative purposes.

### 4.3.2 Individual Network Connectivity Measures

The methods used in this chapter follow closely from Wheeler and O'Kelly (1999), and are similar to techniques described in some detail in Taaffe, Gauthier, and O'Kelly (1996). Begin with a set of nodes, each with a unique identification number from \( i = 1, \ldots, N \), and a set of backbones, \( k = 1, \ldots, B \). Each backbone is made up of set of connections between a subset of the \( N \) nodes. Consider the following notation, paying careful attention to the underscored variables:
N_k indicates the set of nodes in the kth network; (k is not a subscript),

N^k is the number of nodes in the kth network,

B_i indicates the set of networks in which node i appears; (i is not a subscript),

B^i is the number of networks in which node i appears.

These notational conventions are utilized in Table 4.3. In the context of the small illustrative example (shown in Table 4.4), backbone 3 may have nodes N_3= \{1,2,7,9,10\} and thus N^3 = 5. Clearly from the example, each node may appear in one or many networks, and each network may have anywhere from a few to a large number of nodes, node 9 appears in the largest number of backbone networks: B^9 = 5 and they are listed in B_9 = \{1,2,3,5,6\}. On the other hand, network two (N^2 =6) has the largest number of associated nodes N_2 = \{2,3,5,7,8,9\}.

Consider also \( A_{ik} = 1 \) if node i is in network k. Then the number of nodes in network k is

\[ \sum_i A_{ik} = N^k, \quad k = 1, \ldots, B. \]

Similarly the number of networks that node i occurs in is \( \sum_k A_{ik} = B^i, \quad i = 1, \ldots, N. \)

Finally,

\[ N_k = \{i \mid A_{ik} = 1\} \] is the index set of nodes in network k.

\[ B_i = \{k \mid A_{ik} = 1\} \] is the index set of the backbone networks in which node i appears.

Recalling that nodes are numbered from i= 1, ..., N, backbones are numbered from k = 1,...,B, define a matrix of size N^k x N^k, one for each backbone k = 1, ..., B with elements that convey the number of connections between the nodes in the kth network. Combining all the networks into one produces an aggregated matrix of size N x N.

The connection matrix for the kth backbone is \( X^k_{ij} \) which is the number of direct links between i and j.\(^{12}\)

So far this methodology has concentrated exclusively on the presence or absence of links between nodes, and has not made full use of the type or value of the infrastructure on those links. In all the following notes a k superscript denotes the kth backbone.

\(^{12}\) This can be greater than 1 even for a single network backbone, and certainly in the combined network there are many pairs connected by multiple pieces of infrastructure.
### Table 4.3: Notational Conventions

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<th>B</th>
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<th>#</th>
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</table>

**Node**

- \( \sum_{i=1}^{N} A_{ik} = N^k \)
- \( \sum_{k=1}^{j} A_{ik} = B^i \)

**Nodes in network**

- \( N \)
- \( N_1 \)
- \( N_2 \)
- \( ... \)
- \( N_k \)
- \( ... \)
- \( N_B \)

**Backbone networks**

- \( B^1 \)
- \( B^2 \)
- \( ... \)
- \( B^i \)
- \( ... \)
- \( B^N \)

**Network**

- \( N \)
- \( N_1 \)
- \( N_2 \)
- \( ... \)
- \( N_k \)
- \( ... \)
- \( N_B \)
Table 4.4: Backbone Analysis – Six Network: Ten Node Example

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</tbody>
</table>

1,4,7,9,10  2,3,5,7,8,9  1,2,7,9,10  1,2,5,6,8  1,3,6,9,10  3,5,7,9
Let \( m \) be a counter that is incremented as the number of two-, three- and so on multiple step paths between nodes are constructed. Initially we are looking at the direct connects, so we define \( C_{ij}^k(1) = X_{ij}^k \) as the number of 1-step paths between \( i \) and \( j \). Similarly \( C_{ij}^k(2) \) is the number of 2-step paths between \( i \) and \( j \). This number may be zero. We essentially wish to progress through as many steps as needed until every \( i \) and \( j \) pair has at least one path between them, on the \( k \)th network.

These cumulative results for the \( k \)th network are defined as \( C_{ij}^k(m) \), or the number of \( m \)-step paths between \( i \) and \( j \). By definition in this model the total number of paths of all types between \( i \) and \( j \) in the \( k \)th network is:

\[
T_{ij}^k = \sum_m C_{ij}^k(m)
\]  

(1)

While this measure has been shown to be somewhat flawed for conventional transportation network analysis, those very weaknesses measure a crucial aspect of Internet communications: namely the presence of redundant (and perhaps unused) paths between pairs of nodes. The idea in counting ALL possible 1-, 2- and multi-step paths between nodes is that we are thereby measuring the capability of nodes to interact though a multiplicity of alternative routings. This capability is a desirable feature in backbone networks that may become congested. Further, nodes with high degrees of total accessibility are arguably better positioned to survive network congestion than those that are peripheral with few choked connections to the remainder of the network. These are ideas which are testable through empirical measurement, and the analyses to be presented will argue that the measurements provide useful benchmarks of comparative nodal accessibility.
4.3.3 Aggregate Network Connectivity Measures

As the previous discussion suggests, there is the potential for a single node to be located on a wide variety of backbone networks. This is not uncommon considering the role of certain cities as high-traffic “peering” points for the commercial Internet. For example, San Francisco, New York, Chicago, and Washington DC are home to major network access points (NAP) where a wide variety of backbone providers interconnect to exchange traffic directly between networks. Therefore, in addition to considering individual network measurements, a more complete picture of city accessibility to the Internet is obtained by examining the aggregate characteristics of commercial Internet backbones.

Define the combined network as: \( X = \sum_k X^k \). The combined network is: \( C_{ij}(1) = \sum_k X_{ij}^k \), where matrix operations can be shown to yield the multi-step paths:

\[
C_{ij}(m) = \sum_l C_{il}(m-1) * X_{lj} \text{ for } m = 2 \text{ to the diameter of the network}
\]

Define \( D_{ij} \) as a measure of paths between a pair of nodes in a network. Since we are presently unconcerned with the values in these links, we are assured that as soon as a link is established between the pair of nodes, the stage \( m \) at which this occurs can be used as a measure of the number of paths necessary to connect the two places. The total accessibility matrix (\( T \)) can be calculated as follows:

\[
T_{ij} = \sum_{m=1}^{\infty} C_{ij}(m) = C_{ij}(1) + C_{ij}(2) + ... + C_{ij}(\infty)
\]

\[
= X_{ij} + \sum_{m=2}^{\infty} C_{ij}(m)
\]
which is clearly the sum of the 1-, 2-, … \(D\)-Step paths between \(i\) and \(j\), where by definition \(D\) is the stage at which every \(i\) and \(j\) pair has an available path. Since the links are regarded as undirected between two nodes, an entry for the \(i\) and \(j\) pair is placed in \(X_{ij}\) and \(X_{ji}\). Thus,

\[
\sum_j X_{ij}
\]

is the number of links in and out of a node. The degree of the node is therefore

\[
\left(\sum_j X_{ij}\right)/2.
\]

The sum of the degrees of all nodes in the network (or subnetwork if partial networks are being considered) is the number of undirected (two-way) links in the network.

If we analyze the individual backbones separately and then as a composite, it is reasonable to expect that the sum across all networks of the degree of the nodes is the same as the degree of the nodes in the blended backbone network. This consistency check provides a useful measure to ensure that the processing of disaggregations of the total combined network are carefully and properly coded.

The Shimbel distance or \((D)\) matrix is computed as follows: If \(X_{ij} = 0\) then there is no direct path between the nodes, though if \(X_{ij} > 0\) there is at least one path so \(D_{ij} = 1\). Then for further iterations, any linkage which is as yet unconnected, remains undefined until at least one path opens between the nodes, and then \(D_{ij}\) is indelibly colored with the value \(m\). The total accessibility and the total number of paths needed to reach all the nodes in the combined network from a specific base point is:

\[
T_i = \sum_i T_{ij} \text{ for all } i.
\]

\[
D_i = \sum_i D_{ij} \text{ for all } i.
\]

It is these measures that are used to give city accessibility ratings later in the chapter.
4.4 Network Accessibility Results

4.4.1 Individual Networks

In order to better understand city accessibility to the commercial Internet, it is worthwhile to examine several topological measures of the individual backbone networks. For comparative purposes, Table 4.5 displays these topological measures for 1997 and Table 4.6 displays topological measures for 2000. Each backbone network is provided a rank according their D-matrix and T-matrix values. The number of nodes, links, and the gamma index (a measure of overall connectivity) are also displayed\(^\text{13}\). For Table 4.5, all data are recomputed from Wheeler and O’Kelly (1999) with minor adjustments stemming from a correction to a sub-graph discovered in the UUNET backbone. Not only does this verify the previously published work, extending the chart with four new variables, it also provides a platform upon which to compute 2000 characteristics\(^\text{14}\).

D-matrix rankings are based on the number of direct connections (fewest paths between nodes on the individual networks. As Wheeler and O’Kelly (1999) note, there should be a strong negative correlation between D-matrix and T-matrix ranks. This suggests that smaller networks with more direct connections between cities display higher D-matrix rankings than networks with a larger number of connections serving a diverse set of cities. The Spearman rank correlation coefficient between T-matrix and D-matrix values for 2000 is -0.952 (p-value = .0001). Not surprisingly, one of the smallest networks, Lightning Internet, has the highest D-rank. Serving a select set of coastal locations and an emphasis on transcontinental service, the only interior city served by Lightning Internet is Chicago. Accordingly, the T-rank for Lightning Internet is quite low (36th). At the opposite end of the network spectrum is Qwest. Serving a significantly larger number of cities with a network that utilizes both short and long-haul connections, the D-rank for Qwest is low (41), but the T-rank is high (1). As one might expect, because Qwest serves such a

---

\(^{13}\) Recall that a gamma index of one suggests a maximally connected network.

\(^{14}\) Graph theoretic measures for an undirected, non-planar graph (v = vertice; e = edge): 1) emax = v(v-1)/2; 2) gamma = e / emax; 3) alpha = [e - v + 1] / [emax - (v-1)]; 4) cyclomatic # = emax - (v-1) = emax - v + 1.
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<th>T-RANK</th>
<th>LINKS</th>
<th>NODES</th>
<th>CYCLO*</th>
<th>ALPHA</th>
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* Cyclomatic number

Table 4.5: 1997 Network Measures for Individual Backbones
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* Cyclomatic number

Table 4.6: 2000 Network Measures for Individual Backbones
Source: Computed from data listed in text, current as of March 2000
large number of cities, the gamma index of 0.0220 is the lowest of all backbone networks. This result is indicative of a more general trend. The Pearson correlation coefficient of -.611 (p-value = .0001) between the gamma index and the number of nodes served by each network implies the financial constraints of constructing a fully connected network are significant. Instead of attempting to serve all city pairs with direct connections, the construction of a hub-and-spoke network is an attractive alternative for many network providers (Wheeler and O’Kelly, 1999). Hub-and-spoke networks utilize a select set of cities to connect a much larger set of locations together. For example, Fiber Network Solutions utilizes Columbus, Ohio as a hub to connect the cities of Akron, Dayton, Cincinnati, Cleveland, Indianapolis, and Fort Wayne. This type of network configuration is reflected by the relatively lower gamma index of 0.2424. Finally, from a temporal standpoint, overall individual network connectivity appears to be decreasing. In 1997, approximately 22.5% of the backbone networks displayed gamma indices of 40% or greater. However, only 12% of the networks in 2000 have gamma indices of 40% or greater. Again, it is possible that backbone providers are paying more attention to the topological configuration of their networks due to the intense competition within the industry. By adopting configurations that are not fully meshed and redundant (but still providing enough redundant paths to avoid interruption of service), providers are able to avoid the extra capital outlays required in constructing a fully interconnected network. This is often accomplished with multiple peering agreements (Malecki and Gorman, 2000). This is also supported by an overall decrease of alpha indices for the networks as a group. 38.7% of the networks in 1997 displayed an alpha index greater than or equal to 10%. This decreased to 31.7% in 2000. At the same time, overall network sizes (cyclomatic #) and complexities (beta) increased. For example, the largest network in 2000 (Qwest) is nearly 60% larger than the largest network in 1997 (UUNET). Similar increases in network size are documented in Tables 4.4 and 4.5. Finally, approximately 16% of the networks displayed a beta value greater than or equal to 2 in 1997, while 24% did in 2000.
4.4.2 City Accessibility

A number of interesting shifts occurred in the city accessibility rankings between 1997 and 2000 (Table 4.7). Not surprisingly, Chicago, Washington, Dallas, Atlanta, New York, San Francisco, and Los Angeles remain firmly entrenched at the top of the rankings, with only minor shuffling within the top 7 cities. Figure 4.4 illustrates the varying geography of city accessibility, with larger graduated symbols representing better access. For the year 2000, Chicago attains the distinction of being the most accessible city on the commercial Internet in terms of total paths available. As Table 4.7 indicates, there are $1103.5 \times 10^{11}$ ways of reaching all other cities on the commercial Internet from Chicago. Compared to the top ranked city in 1997 (Washington), this represents a massive increase in total accessibility. This level of growth is apparent in all of the T-matrix rankings for the top 30 cities. Even at # 30, the T-matrix value for Orlando represents a 634% increase over Washington in 1997. In fact, the overall growth of interconnection on the commercial Internet between 1997 and 2000 is so great that if one transposed the current T-matrix scores from 2000 back to 1997, Washington would be tied with El Paso for total accessibility at 80th place.

A somewhat surprising result is Chicago’s position at 1st in the D-matrix rankings. As the D-matrix value indicates, it takes 444 steps to reach all other cities from Chicago. The top-ranking city for 1997 was Washington, with a D-matrix score of 269. This means that the number of paths needed to reach all cities in the network has increased 65%, indicative of a significant expansion in the geographic reach and topological structure of the commercial Internet. For example, in 1997, Wheeler and O’Kelly reported that seven of the top twenty D-matrix accessible cities were in the Northeast (Washington, New York, Boston, Philadelphia, Vienna, Pittsburgh, and Newark). In 2000, the geography of city accessibility has shifted west. Figure 4.5 illustrates this shift, with larger graduated symbols representing better city accessibility. Eight of the top twenty cities are now located in the West, six in the South, four in the Midwest, and only two in the Northeast. This suggests that the comparative advantage in access times once enjoyed in
Figure 4.4: T-Matrix Values - 2000

Total Paths

800.01-1103.5
290.21-800
100.01 - 290.2
50.01 - 100
10.01 - 50
0 - 10
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<td>224.3</td>
<td>600</td>
<td>28 (30)</td>
<td>52 (70)</td>
</tr>
<tr>
<td>Detroit</td>
<td>215.0</td>
<td>560</td>
<td>29 (19)</td>
<td>24 (23)</td>
</tr>
<tr>
<td>Orlando</td>
<td>210.0</td>
<td>524</td>
<td>30 (43)</td>
<td>15 (36)</td>
</tr>
</tbody>
</table>

\(^*\) 1997 rankings in parentheses

**Bold** indicates an increase of at least 5 position in the rankings
Shaded indicates a decrease of at least 5 positions in the rankings

Table 4.7: City Accessibility Ranking for Top 30 T-Matrix Values
Figure 4.5: D-Matrix Shortest Paths - 2000
the Northeast has probably shifted to the Midwest and West. In addition, the T-matrix rankings for 2000 indicate that western cities maintain a comparative advantage in case of linkage failure (Wheeler and O’Kelly, 1999).

In addition to the significant increases in T-matrix and D-matrix values, Table 4.7 also highlights the cities which made jumps or drops of more than five positions in the rankings for both measures. For example, the city of Denver moved from 15th place in the total accessibility rankings for 1997 to 8th position for 2000. Similarly, Denver moved from 25th in the D-matrix rankings (shortest path) for 1997 to 10th for 2000. The largest overall increase in city accessibility in both T-matrix (40 positions) and D-matrix (54 positions) rankings is Sacramento. Other significant movements in the T-matrix rankings include cities such as Portland, Indianapolis, Las Vegas, and Salt Lake City. Many of these same cities also moved up significantly in the D-matrix rankings, along with Austin, St. Louis, San Diego, and Orlando. Only one city in the top 30 moved up in the T-matrix rankings and down in the D-matrix rankings, Cleveland. This suggests that although Cleveland is benefiting from more overall connections, access speeds for end users might be slowing due to the increasing prevalence of indirect connections.

4.4.3 Metropolitan Area Accessibility

Previous efforts documenting network accessibility to the commercial Internet aggregate data to metropolitan statistical areas or consolidated metropolitan statistical areas (MSA/CMSA) when appropriate. Several authors suggest that MSAs represent the relevant economic region for analysis of the digital economy (Moss and Townsend, 2000; Malecki and Gorman, 2000; Grubesic and O’Kelly, 2001). Table 4.8 displays the T-Matrix scores for both 1997 and 2000 that result from the MSA/CMSA aggregations. This measure of relative metropolitan accessibility suggests that the San Francisco-Oakland-San Jose CMSA, not Chicago-Gary-Kenosha, is the most connected region in the United States. As one might expect, there were minor shifts in the

---

15 The aggregation results for Table 4.7 and the MSA/CMSA rankings do not represent additional graph-theoretic calculations. Instead, the T-matrix values for all cities on the commercial Internet are aggregated (summed) to the appropriate MSA/CMSA. Therefore, instead of interpreting these results as absolute accessibility scores, they must be interpreted as relative accessibility scores for any given location within the CMSA.
<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>San Francisco-Oakland-San Jose*</td>
<td>1</td>
<td>2</td>
<td>201,772</td>
<td>6,673,645</td>
<td>9,405</td>
</tr>
<tr>
<td>Washington-Baltimore DC-MD-VA-WV*</td>
<td>2</td>
<td>1</td>
<td>208,159</td>
<td>7,359,044</td>
<td>1,969</td>
</tr>
<tr>
<td>Chicago-Gary-Kenosha*</td>
<td>3</td>
<td>4</td>
<td>221,738</td>
<td>8,885,919</td>
<td>3,051</td>
</tr>
<tr>
<td>Dallas-Fort Worth*</td>
<td>4</td>
<td>5</td>
<td>183,571</td>
<td>4,909,523</td>
<td>1,910</td>
</tr>
<tr>
<td>New York-NJ-CT-PA*</td>
<td>5</td>
<td>3</td>
<td>234,258</td>
<td>20,196,649</td>
<td>7,633</td>
</tr>
<tr>
<td>Los Angeles-Riverside-Orange County*</td>
<td>6</td>
<td>7</td>
<td>140,649</td>
<td>16,036,587</td>
<td>4,500</td>
</tr>
<tr>
<td>Atlanta</td>
<td>7</td>
<td>6</td>
<td>149,200</td>
<td>3,857,097</td>
<td>1,045</td>
</tr>
<tr>
<td>Denver-Boulder-Greeley*</td>
<td>8</td>
<td>14</td>
<td>97,545</td>
<td>2,417,908</td>
<td>1,143</td>
</tr>
<tr>
<td>Seattle-Tacoma-Bremerton*</td>
<td>9</td>
<td>12</td>
<td>109,510</td>
<td>3,465,760</td>
<td>1,418</td>
</tr>
<tr>
<td>Houston-Galveston-Brazoria*</td>
<td>10</td>
<td>8</td>
<td>80,483</td>
<td>4,493,741</td>
<td>1,567</td>
</tr>
<tr>
<td>Philadelphia-Wilmington-Atlantic City*</td>
<td>11</td>
<td>11</td>
<td>74,167</td>
<td>5,999,034</td>
<td>2,328</td>
</tr>
<tr>
<td>St. Louis</td>
<td>12</td>
<td>13</td>
<td>69,031</td>
<td>2,569,029</td>
<td>743</td>
</tr>
<tr>
<td>Phoenix-Mesa</td>
<td>13</td>
<td>10</td>
<td>45,868</td>
<td>3,013,696</td>
<td>1,152</td>
</tr>
<tr>
<td>Kansas City</td>
<td>14</td>
<td>18</td>
<td>89,292</td>
<td>1,755,899</td>
<td>277</td>
</tr>
<tr>
<td>Salt Lake City-Ogden</td>
<td>15</td>
<td>28</td>
<td>87,624</td>
<td>1,275,076</td>
<td>474</td>
</tr>
<tr>
<td>Boston-Worcester-Lawrence*</td>
<td>16</td>
<td>9</td>
<td>75,044</td>
<td>5,667,225</td>
<td>3,806</td>
</tr>
<tr>
<td>Cleveland-Akron*</td>
<td>17</td>
<td>16</td>
<td>61,671</td>
<td>2,221,181</td>
<td>1,070</td>
</tr>
<tr>
<td>Portland-Vancouver*</td>
<td>18</td>
<td>29</td>
<td>68,174</td>
<td>2,180,996</td>
<td>964</td>
</tr>
<tr>
<td>Miami-Fort Lauderdale</td>
<td>19</td>
<td>20</td>
<td>42,138</td>
<td>3,711,102</td>
<td>601</td>
</tr>
<tr>
<td>Indianapolis</td>
<td>20</td>
<td>35</td>
<td>39,484</td>
<td>1,536,665</td>
<td>544</td>
</tr>
<tr>
<td>Las Vegas</td>
<td>21</td>
<td>30</td>
<td>42,414</td>
<td>1,381,086</td>
<td>165</td>
</tr>
<tr>
<td>Detroit-Ann Arbor-Flint*</td>
<td>22</td>
<td>17</td>
<td>53,262</td>
<td>5,469,312</td>
<td>2,452</td>
</tr>
<tr>
<td>Sacramento-Yolo*</td>
<td>23</td>
<td>42</td>
<td>41,036</td>
<td>1,585,429</td>
<td>398</td>
</tr>
<tr>
<td>Austin-San Marcos</td>
<td>24</td>
<td>22</td>
<td>32,884</td>
<td>1,146,050</td>
<td>1,571</td>
</tr>
<tr>
<td>Minneapolis-St. Paul</td>
<td>25</td>
<td>15</td>
<td>29,734</td>
<td>2,072,109</td>
<td>2,181</td>
</tr>
<tr>
<td>San Diego</td>
<td>26</td>
<td>23</td>
<td>42,062</td>
<td>2,820,844</td>
<td>1,748</td>
</tr>
<tr>
<td>Orlando</td>
<td>27</td>
<td>32</td>
<td>45,528</td>
<td>1,535,004</td>
<td>200</td>
</tr>
<tr>
<td>New Orleans</td>
<td>28</td>
<td>37</td>
<td>32,777</td>
<td>1,305,479</td>
<td>136</td>
</tr>
<tr>
<td>Charlotte-Gastonia-Rock Hill</td>
<td>29</td>
<td>33</td>
<td>35,441</td>
<td>1,417,217</td>
<td>260</td>
</tr>
<tr>
<td>Pittsburgh</td>
<td>30</td>
<td>19</td>
<td>25,178</td>
<td>2,331,336</td>
<td>809</td>
</tr>
</tbody>
</table>

* Consolidated Metropolitan Statistical Area
**Source: Edward J. Malecki - Department of Geography, Ohio State University
***Source: U.S. Patent & Trademark Office, 1999

Table 4.8: MSA/CMSA Accessibility Ranking for Top 30 T-Matrix Values
overall rankings at the MSA level, but the Big 7 metropolitan areas remain at the top, and the spatial distribution of metropolitan areas exhibiting high accessibility remain skewed to the West (Figure 4.6).

Other general trends include the emergence of several metropolitan areas with excellent accessibility, straddling the Interstate 70 corridor. These areas include Indianapolis, St. Louis, Kansas City, and Denver. As Malecki (2001, 13) suggests, these metropolitan areas benefit from their central location, “serving as intermediate hubs in the transcontinental routes, much as they served as break-of-bulk points in earlier transportation networks.” Other metropolitan areas are also benefiting from infrastructure investment, including the Portland-Vancouver MSA, which moved from 29th in 1997 to 18th in 2000. As the results from Chapter 3 suggest, Portland not only benefits from its location between Seattle and San Francisco, but the local economy is increasingly fueled by businesses rooted in information technology. For example, both Intel and Tektronix maintain several sprawling campuses on the west side of Portland, an area known as “Silicon Forest” (Cortright and Mayer, 2001).

Similar to the T-matrix and D-matrix scores at the city level, the Sacramento area continues to display a remarkable rise in network connectivity and accessibility, moving from 42nd place in 1997 to 23rd in 2000. This dramatic increase in rankings can be attributed to a number of factors. First, both downtown Sacramento and portions of West Sacramento have been targets of significant infrastructure investment over the past two years. Over 10 different Internet service providers have constructed data centers in Sacramento, including major national ISPs such as XO Communications, Williams Communications, and Level 3 Communications. Data centers are best described as massive climate controlled buildings which house a variety of interconnection equipment such as routers, Internet servers and switches. They are usually constructed in locations where fiber optic backbones merge in metropolitan areas. Not surprisingly, this makes the downtown core or “edge city” business parks desirable locations. Data centers in Sacramento range in size from 10,000 square feet to 117,000 square feet (Larson, 2001). In fact, Sacramento has experienced such a massive building boom that the city council recently passed
Figure 4.6: MSA/CMSA Accessibility (T-matrix sums)
an ordinance limiting the installation of telecom data centers in the downtown area for fear that retail and tourism would be negatively affected (McCarthy, 2000).

Finally, correlation coefficients were calculated to measure the general relationship between city accessibility (T-matrix scores), population, utility patent registrations, and backbone capacity. The Pearson correlation coefficient for T-matrix sum and population was .619 (p-value = .000), T-matrix sum and bandwidth .957 (p-value = .000), and T-matrix sum and utility patents .678 (p-value = .000). These correlations suggest several things about the demand for network infrastructure. First, there is a moderate positive relationship between city size and Internet accessibility. As Wheeler and O'Kelly (1999) suggest, if population is the only surrogate used for demand, the Internet infrastructure supply does not match demand for 2000. However, network bandwidth is also considered a surrogate for demand as it is “supplied in response to demand – actual or anticipated – for data transmission” (Malecki, 2001, 14). In this case, interpreting the strong positive relationship between bandwidth and the T-matrix sum is quite intuitive; more bandwidth is available in the cities maintaining an abundance of network connections. One final surrogate for demand is utility patents, otherwise known as “patents for invention”. As Cortright and Mayer (2001) suggest, high technology industries are defined by their ability to continually develop new products or processes. Therefore, because utility patents serve as beacons for innovative activity, one can associate high densities of patent registrations with areas more inclined to demand telecommunication capacity and Internet access. With a moderately strong correlation coefficient of .678 (p-value = .000), results suggest this might indeed be the case.

4.5 Summary

The unprecedented growth of Internet infrastructure between 1997 and 2000 has made basic network analysis of the Internet even more complex. Where individual provider networks are concerned, there exists a wide range of network configurations and competitive strategies. When comparing the gamma indices for 1997 and 2000, it is clear that many providers have moved away from the fully connected mesh to a sparser topological configuration. This suggests
an increasing reliance on peering between network providers. Unfortunately, determining which networks peer and the locations where peering takes place continues to be difficult (Malecki, 2001).

As a group, the most accessible cities on the U.S. commercial Internet have changed very little between 1997 and 2000. Chicago, Washington, Atlanta, Los Angeles, New York, San Francisco, and Dallas remain at the top of a rapidly developing accessibility hierarchy (Gorman and Malecki, 2000; Moss and Townsend, 2000). It is the emergence of the second and third tier cities identified in this chapter that represents the most significant changes in over the past three years. Cities such as Portland, Kansas City, St. Louis, and Salt Lake City have become important nodes on the commercial Internet for a variety of reasons. For example, relative location (along the I-70 corridor) and a local economic base rooted in information technology (Portland) continue to spur infrastructure investment. Although results indicate that the Big 7 will probably continue their dominance in network accessibility, it is possible for smaller cities to make significant jumps in the rankings, as demonstrated by Sacramento, Orlando, and Las Vegas. A final point worth mentioning is the subtle difference between city rankings and MSA/CMSA rankings. As Moss and Townsend (1997) suggest, edge cities (Garreau, 1991) are significant forces in attracting infrastructure development and Internet activity. Therefore, when accessibility scores are aggregated to reflect the MSA/CMSA, a more regional focus incorporating both suburban and exurban development is utilized. To a certain degree, this helps explain the entry of New Orleans (28th), Charlotte-Gastonia-Rock Hill (29th) and Pittsburgh (30th) into the top 30. The next chapter will examine the regional aspects of Internet activity and presence and help clarify the role of Internet activity related to edge cities.
5. Introduction

In a recently issued statewide report, the Technology Policy Group from the Ohio Supercomputer Center evaluated the state of Ohio's readiness for the newly emerging information economy. It documents "Ecom-Ohio’s landmark public-private leadership effort to measure Ohio’s readiness for global electronic commerce" (Ecom-Ohio 2000). The project collected data on 22 key indicators that measure Ohio’s performance against a comprehensive set of national benchmarks created by the Computer Systems Policy Project (CSPP) (Ecom-Ohio 2000). The CSPP benchmarks include evaluations of network infrastructure (availability of local backbone and transmission capacities), types of access (dial-in, ISDN, xDSL, wireless), affordability of services, quality of services, and competition (national, regional, or local providers). The CSPP also sets benchmarks for community use (citizens, business, and government).

According to the Ecom-Ohio study, the state of Ohio’s Internet presence is growing at a staggering rate. "(N)etwork traffic doubles every six months and forecasts show that business-to-business e-commerce will be a major driver of Ohio’s economy in the next decade, generating new entrepreneurial ventures, sources of wealth, and jobs" (Ecom-Ohio 2000). Results of this study also suggest that growth in Ohio is uneven. In fact, there is a significant amount of regional

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16 This chapter represents a revised and expanded version of a paper submitted to Telecommunications Policy. I gratefully acknowledge the support provided by the Ecom-Ohio team and the Ohio Supercomputer Center – which supplied the domain name data used for analysis in this chapter.
variation in Internet presence and activity. For example, Cleveland and its surrounding suburbs have significantly more Internet activity than the rural towns of southeastern Ohio (Appalachia).

As Compaine and Weinraub (1997) note, a goal of the Telecommunications Act of 1996 was to provide access to advanced telecommunication and information services to all regions of the United States. The equitable provision of such services, however, hit snags with increased competition and the elimination of cross-subsidies that supported universal service in the federally regulated market. As a result, the rollout of advanced telecommunication services in rural areas has been slow – having the potential to adversely effect rural economies (Strover, 2001). Previous research has addressed the fundamental differences in Internet activity between urban and rural locations. For example, Downes and Greenstein (1998a) explored the geographical distribution of points of presence (POP) used by Internet service providers, emphasizing the differences between rural and urban connectivity options. Results suggest there are strong correlations between locations with low population densities and no Internet service providers, with approximately 20% of the US population living in these underserved locations. Given this evidence, the authors suggest the presence of multiple POPs, whether national tier, regional tier, or local tier, is an urban phenomenon. Other research examines the prospects rural locales have in terms of telecommunications development, including: regional economic improvement linked to investment in telecommunications infrastructure, gaps in broadband digital networks, and community initiatives for the improvement of telecommunication services (Parker, 2000; Korsching et al., 2001; Lasley et al., 2001; Lentz and Oden, 2001). Finally, Strover (2001) explores telecommunication infrastructure gaps between rural and urban areas, highlighting the effects of deregulation and competition on consumer choice in Iowa, Texas, West Virginia and Louisiana. Results suggest that the high costs associated with rural telecommunication infrastructure (on the provider side) inhibit infrastructure development and service availability.

One of the more significant gaps in the literature centers on the exploration of the contextual elements (infrastructure, access options, economic base, etc.) that promote these differences at smaller geographic scales. The purpose of this paper is to provide a spatial
analysis of Internet presence and activity at a very local level (zip code) and a more regional level (counties) in the state of Ohio. This chapter attempts to establish a link between patterns of Internet activity and the locations in which this activity is taking place by incorporating an analysis of several important contextual variables, including population, existing businesses, and transportation infrastructure. In addition, this paper seeks to construct an analytical framework from which clusters of Internet presence can be identified at both the local and regional level simultaneously. These types of local and regional analyses are important in two ways. First, very little empirical work exists comparing Internet activity and presence at smaller geographic scales. Most work centers on comparisons between countries (Zook, 2000b), regions composed of states, (NTIA 2000; Moss and Townsend, 1998) or individual states (Moss and Townsend, 1998). Work at sub-regional scales predictably centers on consolidated metropolitan statistical areas (CMSA) or metropolitan statistical areas (MSA) for comparative purposes (Moss and Townsend, 1997b). This work fails to include disaggregate data on smaller urbanized communities, thereby masking many interesting patterns at the sub-metropolitan level. Second, by understanding which communities and regions are more competitive where information technology and Internet presence are concerned, telecommunication policy analysts are better equipped to make decisions regarding initiatives for the deployment of Internet infrastructure, at all levels (local, regional, national). This is especially critical considering the increasingly competitive and commercialized industry for Internet access and its subsequent ramifications on the infrastructure equity and the "digital divide" (Malecki and Gorman, 2000; NTIA 2000).

The remainder of this chapter is organized as follows. Section 5.1 examines ways in which Internet presence and activity can be represented in geographic space through an analysis of domain name registrations. Section 5.2 describes the data and methods used for the analysis of domain registrations. This is followed by a presentation of the results (Section 5.3) and Section 5.4 provides a discussion and concluding remarks.
5.1. Internet Presence

The Internet is a multi-format network that offers a variety of tools to exchange information; from email and telnet, to the more complex audio and visual segment of the Internet known as the World Wide Web. Important components of the WWW include domain name registries. Domain names are the character equivalents to the Internet protocol (IP) addresses that identify every computer linked to the Internet.

There have been numerous attempts to map domain address space for the purpose of spatial and economic analysis. Moss and Townsend (1997b, 1998) utilize domain names to analyze Internet activity for U.S. cities and states. Results indicate a complex hierarchy emerging between regions and cities, with some cities emerging as “information hubs.” Additional research examines the spatial organization of the Internet industry in the US and Great Britain via registered domain names and their associated IP addresses (Zook, 1998; Dodge and Shioide, 2000). Other work centers on the diffusion of Internet activity at a global scale by examining generic top level domain registrations (.com, .org, .net) and top level domain registrations by country codes (Zook, 2000b).

There are many advantages to utilizing domain name registrations for spatial analysis. First, the domain name system is administered by the Internet Cooperation for Assigned Names and Numbers (ICANN). All domains registered with ICANN contain basic information about the individual or organization purchasing the rights to a domain name (Table 5.1). Perhaps the most important component of this data is the spatial information contained in the billing address. Given a full address field, it is possible to assign latitude and longitude coordinates (a process known as “geocoding”) to each entry. Once the latitude and longitude coordinates have been assigned, it is then possible to map the distribution of domain registrations for a given geographic area. This spatial representation of domain registrations can be indicative of the varying geographic dimensions of Internet activity and presence. (For a complete discussion on the domain name system, see Wilson, 2001).
Registrant:
Yahoo (YAHOO-DOM)
3400 Central Expressway, Suite 201
Santa Clara, CA 95051

Domain Name: YAHOO.COM

Administrative Contact, Technical Contact, Zone Contact:
Hanley, John P (JPH17)  jh@YAHOO-INC.COM
+1 408 731 3395

Billing Contact:
Billing Administration (NB20-ORG)  billing@NETNAMESUSA.COM
+1 212 627 4599
Fax- +1 212 627 5744

Table 5.1: Domain Name Registration
As Moss and Townsend (1997b) note, domain registration analysis is an excellent way to investigate the social, economic, and policy based trends stemming from Internet use. Because each domain corresponds to a corporate, government, or educational entity, domain names act as surrogate measurements for the adoption and utilization of Internet-based communications by organizations (Moss and Townsend, 1997b). From a temporal standpoint, domain name registrations also contain the date each domain name was first registered. This allows for the identification of regions that had the most rapid growth in Internet activity.

There are some obvious limitations in the transfer of domain registrations to the physical world. First, the address associated with the registrant identification or “owner” of a domain name does not necessarily conform to the location of the machine or IP address serving information. As Dodge and Shiode (2000) suggest, many organizations own an entire block of IP addresses. Further, a single IP address can serve information for a variety of domain names. Therefore, even though all the addresses are registered to the home office (for example, Chicago), many of the IP addresses may be allocated to branch offices around the country. Second, there are no established methods for assigning a weight to each domain name to reflect size, although basic syntax queries into commercial search engines can provide a baseline estimate (Grubesic, 2000). The immense web presence of a company such as Amazon.com weighs no more than a small, locally based retailer (Moss and Townsend, 1998). Finally, given the dynamic nature and rapid changes that occur on a daily basis to the Internet, any analysis of domain registrations can only be viewed as a “snapshot in time.” Despite the aforementioned limitations, the analyses of domain registrations have provided significant insight into the varying spatial characteristics of the adoption of information technology (Moss and Townsend, 1997a, 1998) and their relation to economic processes (Kolko, 1999; Zook, 1998, 2000a; Taylor 2001). For a more complete review, see Chapter 2.
5.2. Data and Methodology

Spatially, this analysis will focus on the state of Ohio, USA, its zip codes, and several of the functional regions within the state of Ohio defined in the E-Com Ohio study (Ecom-Ohio, 2000). Panel 1 of Figure 5.1 illustrates these regions, corresponding to the five major metropolitan areas, their regional hinterlands, and a large block of primarily rural counties located in southeast Ohio. From a geographic standpoint, the state of Ohio provides an interesting backdrop for such a study. Although Ohio is generally considered a heavily urbanized state, its total rural population (27%) is actually higher than the US average (25%). Moreover, levels of economic development, educational attainment, and means of employment are quite varied throughout the state. Therefore, not only does Ohio provide an interesting study area for questions pertaining to disparities in urban and rural Internet activity; Ohio's diverse socioeconomic and demographic patterns provide additional contextual elements worthy of analysis.

In order to establish the significance of several contextual variables relating to Internet activity, two regression models are utilized. Several key variables, including household density, median income, and county level unemployment rate are incorporated into each model. While household density accounts for the settlement geography of each county, measures for median income and the unemployment rate help reflect the wide range of socioeconomic conditions at the county level in Ohio. Three additional variables are utilized to help incorporate locational context into the models, including; dummy variables for the presence of a university or college, interstate frontage, and whether a county belongs to an MSA/CMSA (proxy for urban v. rural). The university/college variable acts as a measure of “community or human capital” (Korsching et al., 2000), while the interstate frontage variable serves as a general measure of access and local infrastructure (Bernal et al., 1991). County level socioeconomic and demographic estimates from 1997 are used as independent variables in the regression analyses.

\[\text{For example, Delaware County (located in central Ohio and part of the Columbus MSA) has a median income of $52,000 and an unemployment rate of 2\%. In contrast, Adams County (located in Appalachian Ohio along the Ohio River) has a median income of $22,000 and an unemployment rate of nearly 11\%.}\]
Figure 5.1: A: Ecom-Ohio Regions
               B: .com Registrations for Ohio Zip Codes
The domain registration data used for analysis at the zip code and county levels are provided by the Ecom-Ohio study for 1999. The actual database consists of all .com, .org, and .net registrations for each zip code in the state of Ohio for 1999. This is a longitudinal database of domain registrations, corresponding to each month (Jan – Dec) for 1999. For the month of December alone, there were over 11,200 registrations in 1014 zip codes in Ohio.

The process of operationalizing these data is fairly straightforward. First, all zip code level domain registration data are placed in a dBase file, with each row corresponding to a zip code and each column corresponding to a month and a specific domain type (.com, .org, .net). The entries in this table represent the total number of domain registrations by type for each month in each zip code. This table is then imported into ArcView, a commercial geographic information system (GIS). Utilizing a zip code boundary file (polygon), the dBase file containing domain registration information is joined with the zip code boundary file to create a comprehensive spatial database of domain registrations for the state of Ohio. Utilizing the S-Plus Spatial Statistics extension in ArcView, statistical analyses at the zip code level are performed. In addition, a custom script written in Avenue calculates location quotients and specialization ratios to determine the extent of Internet presence and activity for each county and their respective region in Ohio.

5.3 Results

5.3.1 Metropolitan Distribution

Figure 5.1 (Panel 2) includes a basic choropleth map that displays the total number of domain names registered for each zip code in the state of Ohio during the month of December 1999. The distribution of registrations is clearly skewed toward the major metropolitan areas of Cleveland, Columbus, Dayton, Cincinnati, Akron, and their surrounding suburbs, mimicking the population distribution for the state.\footnote{It is important to note that these maps contain total domain registrations (.com, .org, and .net)} This is to be expected considering these cities are the centers of industry and commerce in Ohio. A closer look at domain registrations provides a basic
ranking of the top 50 metropolitan areas in Ohio in terms of raw Internet domain presence (Table 5.2).

Although a cartographic analysis of Figure 5.1 suggests a tendency for Internet activity to agglomerate near major urban centers, there are additional tools that can help identify clusters of Internet related activity. Measures of spatial autocorrelation are excellent tools for exploring trends in spatial data. As general descriptive statistics, measures of spatial autocorrelation help determine the interdependence between values of the same variable at different geographic locations (Cliff and Ord 1981; Griffith 1987; Odland 1988; Bailey and Gatrell, 1995). As mentioned previously, Panel 2 of Figure 5.1 suggests that some type of spatial dependence might be present with domain name registrations in Ohio. Zip codes with similar domain registration values appear to be located adjacent to each other. In order to statistically verify the cartographic evidence illustrated, an adjusted first order nearest neighbor test of autocorrelation using Moran’s I was calculated with .com registrations by zip code.

In this case, the value of Moran’s I for .com registrations (0.3094) suggests a significant ($p = 0$), but moderate presence of spatial autocorrelation. In other words, by deriving the distribution of the Moran’s I measure that results from transposing the domain registrations values over all zip codes in Ohio under random and independent assignment, results suggest the random and independent distribution would not produce a Moran’s I larger than the observed value (Odland, 1988).

The results of the adjusted first-order test of spatial autocorrelation certainly suggest the presence of an identifiable pattern or organization to the spatial arrangement of .com domain registrations across Ohio zip codes. Figure 5.2 exhibits further proof by highlighting clusters of similar rates between zip codes. In fact, Figure 5.2 demonstrates the extent to which the value of an observation (.com registrations) is similar or different from its adjusted local neighborhood. In essence, this is an indicator of local spatial association (LISA) (Anselin, 1995). In this case, the neighborhood definition (spatial weights matrix) for Figure 5.2 is the adjusted first order nearest
<table>
<thead>
<tr>
<th>Rank</th>
<th>City</th>
<th>.com (12/99)</th>
<th>Rank</th>
<th>City</th>
<th>.com (12/99)</th>
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</thead>
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<tr>
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<td>29</td>
<td>INDEPENDENCE</td>
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<td>29</td>
<td>BRUNSWICK</td>
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<td>ROCKY RIVER</td>
<td>39</td>
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<td>73</td>
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<td>NORTHWOOD</td>
<td>27</td>
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<tr>
<td>25</td>
<td>GROVE CITY*</td>
<td>45</td>
<td>47</td>
<td>MARION</td>
<td>27</td>
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</tbody>
</table>

* Non-primary city with beltway access to central city

Table 5.2: Top 50 .com Cities - Ohio (1999)
Figure 5.2: Local Clusters of Internet Activity - .com Zip Codes
Results suggest the presence of several significant clusters, largely corresponding to the previous cartographic analysis on domain registrations where urbanized areas were identified as having the most Internet related activity. Indeed, the LISA statistic indicates that the major metropolitan areas of Cleveland, Columbus, Akron, Dayton, and Cincinnati contain several statistically significant local clusters of domain activity.

Given these results, it is worth exploring several contextual elements that might contribute to the development of the clusters identified using this procedure presented in Figure 5.2 and Table 5.2. Nine of the top ten entries in Table 5.2 correspond to the five largest cities in the state (Cleveland, Cincinnati, Columbus, Akron, and Dayton) and their suburbs. Again, these results are quite intuitive. However, there are a number of interesting entries which one might not initially expect to make the list, including the communities of Dublin (pop. 30,000), Westerville (pop. 35,000), and Chesterland (pop. 13,500) (Figure 5.2).

Although these cities have relatively small populations, there are several characteristics that Dublin, Westerville, and Chesterland have in common. First, all three cities are home to many firms “rooted” in information technology and the Internet. For example, Dublin is home to a major branch of Qwest Communications, the 4th largest telecommunications company in the United States and OCLC, the world’s largest online shared cataloging system for libraries. Similarly, Westerville is home to Alliance Data Systems (ADS), a company providing end-to-end credit card processing services for the petroleum, transportation, and retail sectors. Second, all three of these cities are located on the outskirts of major metropolitan areas and have easy access to major Interstate freeways via beltways. To a certain extent, it is possible to classify these municipalities as “edge cities” (Garreau 1991). For instance, let us take the city of Dublin as an example. May 2000 estimates indicate that 2,999,240 square feet of office space are leased in the city. In addition, retail space easily exceeds 600,000 feet when one considers the

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19 First, a spatial weight is defined by using the simple first order neighboring criteria. Then, an average (centroid-to-centroid) distance between the neighboring polygons and polygon i is calculated. A polygon not among those defined as a neighbor will be admitted as a neighboring polygon if its spatial distance (centroid-to-centroid) from the polygon i is less than this average distance.
big-box developments along Dublin’s two major commercial corridors. Further, there are more jobs than bedrooms in the city of Dublin. In other words, Dublin is a destination for workers (the population increases at 9 am). Finally, the city of Dublin is nothing like the city it was thirty years ago. The population of Dublin in 1970 was 681. Therefore, with the exception of leased office space, a category where the city falls short, Dublin can be classified as an edge city under Garreau’s (1991, 4) framework. One final point worth mentioning is the role of interstate highway frontage. Eleven of the top 25 cities/zip codes included in Table 5.2 are located adjacent to a beltway. Further, virtually every city in the top 25 has easy access to an Interstate freeway.

Although the preliminary analysis presented in this section is primarily descriptive, it certainly alerts one to the fact that significant trends are emerging at the local level regarding Internet activity. Initial results indicate edge city style developments (proximity to major central cities), strong transportation infrastructure, and local economies with a high presence of firms active in information technology influence Internet presence. These trends are analyzed more closely at the county, MSA, and regional level later in this section.

5.3.2 Regional Distribution

Although the results thus far are compelling, there is a need for examining domain registrations at the regional level. Chapter 4 of this thesis notes the importance of a multi-scale framework for analysis where city accessibility to commercial Internet backbones is concerned. For example, evaluating a city such as San Jose outside the more important context of Silicon Valley can provide a much different set of results. As such, it is important to consider the idea of emerging regional nodes or centers of Internet-based activity for the state of Ohio. The idea of regional economic competition, innovation, and growth in high-technology sectors continues to be a major theme in the literature (Oakey, 1985; Gordon and McCann, 1998; Simmie and Sennett, 1999). The remainder of this section attempts to identify the presence of regional centers of Internet related activity. Moreover, this section also places special emphasis on contextual
questions concerning the equity of infrastructure investment and access options for each region that might contribute the presence (or lack of) such centers.

Let us begin by examining total domain registrations by county (Panel 1, Figure 5.3). Similar to the analysis of domain registrations at the zip code level, Panel 1 of Figure 5.3 illustrates the tendency for high domain counts in the major metropolitan areas of Cleveland, Columbus, Dayton, Cincinnati, and Akron. Evidence further reinforces disparities in domain presence exist at the county, MSA, and regional level. Consequently, it also suggests that domain registrations might simply be a function of population. 95 percent (19/20) of the top 20 counties (in terms of domain registration) are located in an Ohio MSA. The only county not included, Wayne, shares borders with three separate MSAs (Cleveland, Akron, and Canton). Further support of a skew toward population density is evidenced in Table 5.3. Although the aggregate statistics do a nice job of displaying raw Internet presence, the actual intensity of activity (on a per capita basis) is not readily apparent. In other words, the degree to which a county is specializing in domain activity needs to be determined from these data. Results of this exercise should indicate differences between domain intensity/activity with respect to population, civilian labor force, and firm location.

In order to examine the relationships between registered domain names and population, this section begins with a simple domain per-capita measurement (Panel 2, Figure 5.5). Similar to the results reported in the previous section of this chapter, domain registrations closely mimic the population distribution within Ohio. In fact, the Interstate 71 corridor contains counties that display the highest domain per capita rates in Ohio. Counties such as Hamilton (1.262), Warren (1.389), Franklin (1.727), and Cuyahoga (1.406) all display higher than average rates for domain registrations. However, there are several more notable locations in the state. For example, Geauga County (pop. 83,000 and located directly east of Cleveland) has 4.235 registered domains per 1000 people. This rate can be explained if one revisits the analysis of domains and zip codes in the earlier section. Chesterland, Ohio is located in Geauga County. With over 170

---

20 This classification generally alludes to a more highly populated urban complex.
Figure 5.3: A: Domains Totals by County
B: Domain per 1000 Population
Ohio Counties | 88
---|---
Median .com registrations | 19
Mean registrations | 125
Maximum .com registrations | 1964
Minimum domain registrations | 1
Standard Deviation | 338
% Counties with < 19 domains | 50
% Counties with < 100 domains | 78.40
% Ohio pop. found in counties > 100 domains | 65.32

Table 5.3: County Level domain registrations - Ohio (1999)
total registrations, the 44026 zip code ranks very highly on a statewide basis. In fact, Chesterland placed sixth on the list for .com registrations. Given Geauga County’s comparatively low population, and its proximity to Cleveland, it is clear why Geauga has such a high per-capita rate. The other notable county is Montgomery. One of the reasons that Montgomery County is a significant location for domain registrations is the presence of the city of Dayton. As will be illustrated momentarily, the city of Dayton and its metropolitan statistical area have one of the more unique regional economic structures in the state of Ohio. Given its relatively small population (compared to Cleveland, Columbus, and Cincinnati), the per-capita rate for domain registrations provides an interesting entry point for a brief analysis of Montgomery County and the city of Dayton.

There is a significant relationship between Internet backbone capacity and domain counts. At a national scale, major urban centers dominate in the presence and construction of Internet infrastructure (Wheeler and O'Kelly, 1999; Moss and Townsend, 2000; Gorman and Malecki, 2000). Cities such as New York, Washington DC, San Francisco and Chicago all serve as network access points (NAP) for the commercial Internet. Although these cities dominate in terms of backbone capacity and domain registrations, other smaller cities have a larger presence than their population might suggest. Dayton, Ohio is one of these cities. As with many of the mid-to-large sized localities in Ohio, population estimates for Dayton indicate a decline of nearly 10% between 1990 and 1998. That places the population of Dayton at approximately 167,000. This is much smaller than Cleveland (495,000), Columbus (669,000), or Cincinnati (336,000). However, Dayton has a very strong Internet presence. With six Internet service providers in the Dayton area, backbone capacity approaches 7000 Mbps. There are also high concentrations of military, university, and research facilities in the area. For example, companies such as NCR, Mead, Delphi, and Consolidated Freightway/Emery Air call the Dayton region home. In addition, Wright Patterson Air Force Base is also located in the immediate area. There is no doubt that this type of presence boosts Montgomery County in terms of domains per-capita.
5.4 Incorporating Context through Regression Analysis

Utilizing a log-transformed dependent variable defined as the number of domain registrations in each county, two regression models were constructed to help explain the socioeconomic and geographic characteristics of domain activity at the county level. This subsection provides a solid statistical foundation for the discussion of regional centers of activity found in the next section.

Model 1

The first model displayed in Table 5.4 is a basic ordinary least squares regression, which incorporates the six variables outlined in Section 3. Accounting for 82% of the total variance in Internet activity at the county level, Model 1 includes four significant variables. As the positive coefficients and t-values suggest, household density, median income, the presence of a university or college, and the relative measure of ‘urban’ are key components in helping explain Internet activity. Although not a significant contribution in this model, the measure for unemployment rate at the county level retains a negative coefficient, suggesting the potential for higher unemployment rates to negatively impact Internet activity. Conversely, although the interstate highway frontage variable was not significant, it does retain a positive coefficient.

A standard method for evaluating the reliability and validity of a regression model, especially one dealing with spatial data, is through the use of spatial autocorrelation statistics on the residuals. In this case, the Moran’s I of 0.3617 suggests some source of variation has been omitted from the model (Odland, 1988; Miron, 1984). This variation is addressed in Model 2.

Model 2

In order to better account for the potential spatial bias detected in residuals of the OLS model, a conditional spatial autoregressive model (CAR) was constructed, utilizing the same independent variables as the OLS model. This offers improvement over the traditional OLS model by incorporating the potential spatial dependence of domain registrations at the county level into the modeling parameters. As expected, the significant parameters of the CAR model
# Table 5.4: Regression Model Results

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<thead>
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<th>OLS</th>
<th>Spatial (CAR)</th>
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</thead>
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<tr>
<td>Intercept</td>
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<td>-0.6739</td>
</tr>
<tr>
<td></td>
<td>(-1.124) [0.264]</td>
<td>(-0.749) [0.455]</td>
</tr>
<tr>
<td>Household Density</td>
<td>0.00417</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>(8.659) [0.000]</td>
<td>(8.7983) [.000]</td>
</tr>
<tr>
<td>Median Income</td>
<td>0.0814</td>
<td>0.0804</td>
</tr>
<tr>
<td></td>
<td>(4.112) [0.000]</td>
<td>(3.9848) [.000]</td>
</tr>
<tr>
<td>Unemployment Rate</td>
<td>-0.00825</td>
<td>-0.0583</td>
</tr>
<tr>
<td></td>
<td>(-.146) [0.884]</td>
<td>(-1.0316) [0.305]</td>
</tr>
<tr>
<td>MSA (Urban)</td>
<td>0.611</td>
<td>0.622</td>
</tr>
<tr>
<td></td>
<td>(2.997) [0.004]</td>
<td>(3.1800) [0.002]</td>
</tr>
<tr>
<td>University</td>
<td>1.139</td>
<td>1.133</td>
</tr>
<tr>
<td></td>
<td>(6.178) [0.000]</td>
<td>(6.9527) [0.000]</td>
</tr>
<tr>
<td>Interstate</td>
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</tr>
<tr>
<td></td>
<td>(1.405) [0.164]</td>
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</tr>
<tr>
<td>Rho</td>
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<td>Adjusted R-squared</td>
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<td>----</td>
</tr>
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<td>Adjusted First Order Moran's I</td>
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</tr>
<tr>
<td>Moran's Z</td>
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<td>0.1814</td>
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</table>

$t$-values are shown in parentheses
$p$-values are shown in brackets
displayed in Table 5.4 are not dramatically different from the OLS model. Household density, median income, the presence of a university or college and the relative measure of 'urban' remain significant and positive indicators of Internet activity. The only dramatic difference between the OLS and CAR models is found in the Moran's I measure. The CAR model effectively eliminated the autocorrelation of residual values found in the OLS model, providing more validity in a spatial-statistical context.

5.5 Regional Centers

An alternative method to examine domain registrations is a specialization ratio. One such approach is the location quotient. Developed by Hildebrand and Mace (1950), the location quotient (LQ) approach utilizes a ratio to measure the extent to which an area is specialized, relative to another area, in the production of a particular product (Klosterman 1990). The location quotient is frequently used in economic base studies. For example, the LQ is defined as the ratio of an industry's share of the local economy to the industry's share of the national economy. This general concept of local specialization relative to a larger area (regional or supra-regional) is one worth exploring. By examining which counties and regions in the state of Ohio exhibit a tendency to "specialize" or have more than their share of domain registrations, basic conclusions can be drawn as to which areas are emerging as centers of Internet activity and growth.

Let us begin by examining a basic model for calculating a location quotient. The location quotient for employment can be defined as follows:

\[
LQ_i = \left( \frac{\frac{e^t_i}{e^T_i}}{\frac{E^t_i}{E^T_i}} \right) * 100
\]

where

\( e^t_i \) = regional employment in industry \( i \) in year \( t \);

\( e^T_i \) = total regional employment in year \( t \);
\[ E_i^t = \text{national employment in industry } i \text{ in year } t; \]

\[ E_t = \text{total national employment in year } t; \]

Industries with LQs equal to 100 have a local employment share exactly equal to the national share. Industries with location quotients less than 100 have local employment shares smaller than their national shares. Finally, industries with location quotients greater than 100 have local employment shares which are larger than their national shares (Klosterman 1990).

It should be noted that the inputs for location quotient calculations are typically complete enumerations (counts) of the variable of interest. Therefore, it is quite simple to adapt this same type of ratio for the examination of domain counts and population for each county in Ohio.

\[ \text{LQ}_i = \left( \frac{e_i^t}{e_p^t} \right) \left( \frac{E_t}{E_p} \right) \times 100 \]  \hspace{1cm} (2)

where

\[ e_i^t = \text{total domains in county } i \text{ in year } t; \]

\[ e_p^t = \text{total population (or active businesses) in county } i \text{ in year } t; \]

\[ E_i^t = \text{total domains in region } i \text{ in year } t; \]

\[ E_p^t = \text{total population (or active businesses) in region } i \text{ in year } t; \]

In this version of the location quotient, domain counts and population are substituted for employment. This ratio helps determine whether a county has more or less than its share of domains given its population. Counties with LQs equal to 100 have a share of registered domains exactly equal to the regional share with respect to population. A county with a location
quotient less than 100 has a smaller share of domains than its regional neighbors with respect to population. Finally, a county with a location quotient greater than 100 has a larger share of domains than its regional neighbors with respect to population (or active businesses) and is indicative of a center of Internet activity in this framework.

**Northeast Ohio**

As expected, the highest-ranking county in northeast Ohio is Geauga County (Panels 1 and 2, Figure 5.4). Once again, the combination of its proximity to Cleveland, edge city style development on state highway 322 in Chesterfield, and a relatively low aggregate population make Geauga County unique. Also illustrated in Figure 5.4 are the zip codes registering statistically significant and positive indicators of spatial association from the LISA analysis earlier in this section. Not surprisingly, Figure 5.4 suggests a strong correlation between the results of the specialization ratios and the measures of spatial autocorrelation. Both treatments clearly identify centers of Internet activity, albeit in different ways.

As expected, rural, agricultural counties with high unemployment rates display lower LQs. This trend is not only evident in NE Ohio, but throughout the entire state. For example, Holmes County is one of the most rural locations in the state. With no Interstate access, a high population of Amish Mennonites, and only 97 new business starts in 1998, it is no surprise that Holmes County has only 6 registered domains.

**Northwest Ohio**

Lucas County and the city of Toledo dominate the aggregate domain registrations counts for northwest Ohio and rank fairly high at a statewide level (Table 5.2). What is surprising is that Wood County ranks first in terms of both LQs (Pop. LQ = 177.91; Bus. LQ = 218.81) for northwest Ohio (Panels 3 and 4, Figure 5.4). Perhaps the biggest reason for this difference is the community of Northwood, Ohio. Located on the border of Wood and Lucas Counties, the community of Northwood is Toledo’s version (albeit smaller) of an edge city. Located on the
Figure 5.4: A: Specialization Ratios, Northeast
B: Specialization Ratios, Northwest
Interstate 280 beltway, Northwood contains 60 registered domains. When factors such as Bowling Green State University, 12% more interstate frontage, and the presence of several major corporations are considered, it makes sense that Wood County might display higher LQs than Lucas County. Also of note is the lack of any zip codes registering significant and positive local spatial association for the NW region. One possible explanation for this is the dispersed spatial nature of domain registrations in this area. In essence, although some zip codes do contain high concentrations of domain registrations, they are not proximal to each other. Therefore, one can argue that a community such as Northwood represents an “island” of Internet activity at the zip code level. However, a more regional (versus local) framework of analysis (specialization ratios) demonstrates the importance of Wood and Lucas counties in the NW region. As a result, the importance of a multi-scale approach to examining this problem becomes clear as these areas are not otherwise highlighted.

Southwest Ohio

Southwest Ohio presents an interesting set of results (Panels 1 and 2, Figure 5.5). This is the smallest geographic region in Ohio but one of the more active regions in terms of the Internet. Obviously, the major contributing factor to this activity is the presence of Cincinnati. As far as the location quotients are concerned, Hamilton County (Pop. LQ = 119.77; Bus. LQ = 104.60) ranks highly in the region. There is an interesting disparity in southwest Ohio, that of Clermont County. Although it has less than its share of domains in terms of population (83.15), it has more than its share of domains in terms of business (124.15). Again, if one revisits the geographic characteristics of Clermont County one finds that the Interstate 275 beltway extends throughout the western portion. Similar to the results highlighted in NE and NW Ohio, it appears that counties with interstate frontage and proximity to major metropolitan areas display significant levels of Internet activity in SW Ohio.
Figure 5.5: A: Specialization Ratios, Southwest
B: Specialization Ratios, West
West Ohio

West Ohio is very similar to SW Ohio in terms of regional Internet activity (Panels 3 and 4, Figure 5.5). As discussed previously, the city of Dayton has a significant influence on the type and quantity of activity that takes place in this region (much like Cincinnati in the SW). Of particular interest in this region is Greene County. Although the population LQ is not particularly high (77.44), the business LQ (123.00) is worth mentioning. Greene hosts two major suburbs of Dayton (Beavercreek and Fairborn), a significant amount of Interstate beltway frontage (21.75 miles of I-275), and several universities (Wright State, Cedarville, Central State, and Antioch).

Central Ohio

In contrast to the previous four regions where edge city development and Internet activity spilled into adjacent counties, the county where the primary city is located (Franklin County and Columbus) contains the highest population and business LQs (Panels 1 and 2, Figure 5.6). This is not to say, however, that central Ohio is not without a rapidly growing suburban population in an adjacent county. Delaware County (Franklin’s neighbor to the north) has one the fastest growth rate in the state. Moreover, many of the residents in Delaware County commute to Franklin County for work. 1998 estimates indicate that Delaware County’s population has grown almost 30% since the 1990 Census. Given the results from northeast, northwest, southwest, and west Ohio, why does Delaware County trail Franklin County in terms of the LQs? There are two good reasons for this. First, Franklin County contains 100% of the I-270 beltway. In contrast to counties such as Wood, Clermont, Geauga, and Greene, Delaware County contains no beltway frontage. This creates a situation where the majority of “edge city” style development occurs in Franklin County alone. The aforementioned communities of Dublin and Westerville are good examples of this. Franklin County also benefits from the presence of multiple (high traffic) Interstates (I-70 and I-71). Second, one might suggest that the multi-nodal nature of Franklin County helps perpetuate the clustering of Internet activity. In other words, it makes little sense for
Figure 5.6: A: Specialization Ratios, Central Ohio
B: Specialization Ratios, Southeast Ohio
businesses to locate in Delaware County when all the benefits of an agglomeration economy are found in Franklin County. Not only does Columbus act as a major distribution hub, but it also contains nationally recognized research institutions (Ohio State University, Battelle Memorial Institute) and research labs (Lucent, Abbott).21 Once again, as Figure 5.6 illustrates, the presence of spatially autocorrelated zip codes in Franklin County suggest that both local and regional clustering is occurring.

Southeast Ohio

It is worth mentioning that careful interpretation of the results in Panels 3 and 4 (Figure 5.6) is necessary to fully appreciate the situation in SE Ohio. As a region, SE Ohio accounts for a mere 180 domain names. Athens County alone accounts for almost 33% of these domains. One of the reasons Athens has so much Internet activity can be attributed to the presence of Ohio University. With a student body of nearly 20,000, Ohio University acts as the remote hub for Internet activity in SE Ohio.

The overall dearth of Internet activity in SE Ohio can be attributed to low population and business density. Its rural character does not attract a significant amount of private investment for infrastructure or development. In a period of unprecedented growth on the Internet, it is interesting to note that the number of domains in SE Ohio decreased by 50% during 1999. These results suggest that the urban-rural differences in Internet related activities are accelerating in Ohio. Moreover, regions such as Appalachia (SE Ohio) are quickly being left behind in both infrastructure and activity. Several forces are at work here. Ohio’s portion of Appalachia does not provide an attractive economic environment for businesses involved with Internet related activity. One of the primary reasons for this is the overall lack of Internet infrastructure in the region. The Ecom-Ohio study (1999) indicates that although 622 Mbps connections are common throughout the state of Ohio, the SE region only has access to 45 Mbps lines. More importantly,

21 Franklin County and the city of Columbus are home to Rickenbacker International Airport and Foreign Trade Zone #138. As a joint-use, cargo dedicated, airport, Rickenbacker is served by six airlines; with FedEx operating one of its six U.S. cargo hubs from a 274,000 square-foot (25,500 square-meter) sorting center.
most of this access is provided to the educational institutions serving this area (Ohio University and Shawnee State). This virtually eliminates the possibility of a real high-bandwidth connection serving a business in this region. Second, with workforce characteristics that severely lag those in other parts of the state, both in terms of education and workers available, SE Ohio does not necessarily represent an attractive location for Internet related economic activity.

5.6 Discussion

The results presented in Sections 5.3, 5.4 and 5.5 clearly indicate a marked disparity in Internet activity and presence for the state of Ohio. One might suggest that Ohio is a microcosm of the United States in terms of the social, urban, and economic impacts of the Internet. First, results of the domain registration analysis suggest that several major metropolitan areas of Ohio (Cleveland, Columbus, Cincinnati, and Dayton) and their suburbs are dominating the state where Internet activity is concerned. These results are supported by several spatial analytical measures of Internet related activity, including two regression models, specialization ratios and local indicators of spatial association. Both approaches help illustrate the presence of local and regional clusters of domain registrations and Internet activity. As mentioned previously, this emerging urban hierarchy of Internet activity is well documented at the national level both in Chapters 3 and 4 of this thesis and by other authors (Wheeler and O'Kelly, 1999; Moss and Townsend, 2000; Gorman and Malecki, 2000). Not only are cities such as Washington DC, Chicago, and New York historical centers for economic activity, they are emerging/transfoming into centers of Internet related activity as well. With these trends in mind, the empirical evidence presented in Sections 5.3 and 5.5 forwards the notion of urban domination at the local and regional levels for the state of Ohio. Therefore, although the Internet is able to facilitate communication across significant distances, it has not created the rapid decentralization of economic and social activities that was once predicted (Gillespie and Williams, 1988; Cairncross, 1997). More importantly, the emergence of established urban hubs in Ohio such as Cleveland
and Columbus reinforces the fact that people and economic activity still benefit from clustering in metropolitan areas.

Second, the results presented in this chapter also suggest a new pattern of Internet related activity. The concept of “edge cities” is proving to be robust, especially where the information-based economy is concerned. One of the most recent trends in the commercial backbone and interconnection industry is the rapid growth of co-location facilities, data centers, and “telecom hotels”. Typically, these buildings house interconnection equipment for the telecommunication industry. Edge city style developments are proving to be fertile fields for the construction of such centers. For example, an affiliate of Goldman Sachs (Archon Group) is putting plans in motion to purchase a 21-year-old shopping center in the northern suburbs of Dallas. At 1.3 million square feet, their plans are to turn this vacant retail center into a telecom hotel (Inman, 2000). These types of development, in conjunction with significant amount of office space for rent, and access to major transportation arterials such as Interstate beltways, are revitalizing edge cities across the country. The empirical evidence presented in this chapter (Dublin, Chesterland, and Westerville) certainly supports this trend.

5.7 Summary
This chapter provides empirical investigations of Internet presence and activity at both the local and regional scale for the state of Ohio. Results indicate that Ohio’s major metropolitan areas and their surrounding regions are emerging as hubs for Internet related activity for the state. In addition, “edge city” communities, transportation infrastructure, and the presence of research units such as universities certainly promote Internet activity. Evidence presented in this chapter also suggests that a multi-scale framework for analysis is a valid and important approach to consider when evaluating Internet activity. Finally, evidence suggests that Ohio’s portion of Appalachia, along with more rural (agriculturally based) counties throughout the state are lagging behind the metropolitan strongholds where Internet activity is concerned. The next chapter will
examine the urban and rural divide more closely, paying special attention to local Internet access technologies.
Residential broadband refers to a series of network technologies that promise to deliver high-speed network access to the home. By definition, the Federal Communications Commission defines broadband as the capability of supporting at least 200 Kbps in the consumer’s connection to the network (“last mile”), both from the provider to the consumer (downstream) and from the consumer to the provider (upstream) (NTIA and RUS, 2000). Unlike traditional dial-up services which operate between 28.8 Kbps and 56 Kbps, residential broadband can deliver speeds approaching 2 Mbps. In fact, the ability to access high-speed Internet connections from the home represents one of the most important advances in the evolving information economy (NTIA and RUS, 2000). As Abe (2000) notes, the scale of residential broadband is potentially huge in comparison to business networking. For example, although there are approximately 10 million businesses in the United States, there are over 100 million households. As such, equipment providers such as Cisco and service providers such as BellSouth have the potential to earn millions in revenues as more homes subscribe. In addition, there is little doubt that content providers such as AOL will continue to identify revenue potential in markets such as on-demand video over the Internet, which is largely enabled by higher bandwidth connections (Murphy, 2000).

There are also issues regarding the provision of residential broadband services that are of great consequence. In a recently issued report by the National Telecommunications and Information Administration (NTIA) and the Rural Utilities Service (RUS), evidence suggests that

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22 I gratefully acknowledge the support provided by the Ecom-Ohio team and the Ohio Supercomputer Center, which supplied the central office and xDSL data used for analysis in this chapter.
rural areas are currently lagging far behind urban areas in broadband availability (NTIA and RUS, 2000). In fact, although cable modem and digital subscriber line (xDSL) technologies are making residential broadband a reality, infrastructure investment for these technologies is primarily found in urban and suburban markets. For example, 65% of the cities surveyed in the NTIA study with populations over 250,000 have both cable and xDSL broadband service. However, only 5% of the cities with populations under 10,000 have cable modem service or xDSL service (NTIA 2000). This relative paucity of residential broadband availability in rural areas suggests that the “digital divide” is present in the United States. More importantly, these statistics also indicate that the pro-competitive provisions of the Telecommunications Act of 1996 are not, as yet, benefiting rural and urban areas equally.

Given the aforementioned evidence, the purpose of this chapter is fourfold. First, this chapter examines several of the important telecommunications issues that confront rural America, with particular reference to the state of Ohio. These issues include federal policy, economic development, and the impact of geography on telecommunication infrastructure investment. Second, this chapter provides a current snapshot of broadband cable and xDSL service availability for the state of Ohio. Third, this chapter seeks to develop an explanatory framework regarding xDSL service availability for residential areas in Ohio by analyzing several key contextual variables that are hypothesized to be strong indicators of market demand for broadband xDSL services. These variables include household density, education, income, location, age, and competition from the cable industry. Finally, this chapter reviews local initiatives in several rural communities seeking to improve telecommunication access.

This type of regional analysis on telecommunication infrastructure and service availability is important for a number of reasons. By identifying gaps in broadband accessibility, one can begin to draw basic conclusions regarding the evolution of the digital divide, from a socioeconomic and demographic gap to a divide that reflects a combination of socioeconomic status, demographics, and location. In addition, gaps in broadband access also suggest a need for reevaluating current policies seeking to promote equitable investment in telecommunication
infrastructure. Such gaps are indicative of the need for establishing new policies to improve the distribution of infrastructure investment.

The state of Ohio provides a good location for studies examining the spatial disparities of telecommunication access in a rural-urban framework. With a total population over 11 million, 27 percent (3 million) of Ohio’s residents live in rural areas. Further, 29 of Ohio’s 88 counties are considered “Appalachian Ohio”; an area targeted by federal and state government partnerships seeking to promote economic development, strengthen physical infrastructure, and build local and regional capacity (ARC, 2000). In addition to the rural segments of Ohio, many large urban complexes are also found in the state, including; Cleveland, Columbus, Cincinnati, Dayton, and Akron. Therefore, given the socioeconomic and demographic diversity found in the state of Ohio, one might suggest that trends identified in this state are representative of trends likely to exist throughout the United States.

The remainder of this chapter is organized as follows. Section 6.1 examines issues facing rural communities and their accessibility options to the information superhighway. This section pays special attention to federal policy, economic development, and the role of geography in telecommunication infrastructure investment. Section 6.2 explores the current spatial dimensions of residential broadband for the state of Ohio. This is followed by details regarding the structure of the application study. Results will then be presented, followed by a brief discussion and concluding remarks.

6.1 The Urban-Rural Divide

According to the US Census Bureau, “rural” is defined as towns less than 2,500 in population (US Census, 2000). This also includes areas outside of towns that are classified as farmland, ranchland, or wilderness. Although Ohio is generally considered a heavily urbanized state, its total rural population (27%) is higher than the US average (25%). Figure 6.1 illustrates all of the Census designated places (CDP) in the state of Ohio. The orange areas dotting the landscape represent communities with populations less than 2,500 (rural). It is interesting to note
that many of these rural communities are located in metropolitan statistical areas (MSA). According the Census Bureau, these areas are typically indicative of relatively affluent suburbanizing areas, which are close to a central city. The community of New Albany (northwest of Columbus) is a good example of this phenomenon. The CDPs outside of Ohio MSAs better exemplify areas traditionally thought of as rural. However, these rural communities do not include large portions of Ohio’s rural population living on farmland, ranchland, or wilderness areas. At the national level, people living on farmland, ranchland or wilderness areas account for approximately 11% of the US population. As Figure 6.1 illustrates, these types of settlement patterns are especially prevalent in southeast and northwest Ohio.

As Egan (1996) notes, there is also a need to distinguish between “rural” and “remote” subscribers. Remote subscribers typically experience more difficulty in gaining network access due to the physical remoteness caused by either extreme distance or complex terrain (Egan, 1996).

6.1.1 Universal Service, Natural Monopolies and Deregulation

The roots of the urban/rural divide trace back to the concept of universal service. Historically, the term universal service means, “a telephone network that covers all of a country, is technologically integrated, and connects as many citizens as possible” (Mueller 1997, 1). This concept originated in the early 1900s, a critical time in the development of the American telecommunications system. In fact, the term was coined in the 1910 annual report by AT&T, stating, “The telephone system should be universal... affording opportunity for any subscriber of any exchange to communicate with any other subscriber of any other exchange... some sort of connection with the telephone system should be within the reach of all” (Tunstall, 1985). Rather than simply casting universal service as a positive social goal, AT&T mentions this provision in the spirit of competition. During this timeframe, numerous independent telephone companies were battling with AT&T to become profitable telephone providers. As such, the value of each network was directly tied to its geographic reach (Caristi, 2000). By attempting to extend the
reach of AT&T’s network through universal service, the overall value and profitability of AT&T would be greatly enhanced.

By 1934, universal service was widely accepted as an important goal for the United States (Robinson, 1989). As AT&T’s network continued to grow, so too did its grip on the telecommunication industry. Although the United States has always favored competition amongst privately held telecommunication companies, it is during this era when AT&T began operating as a natural monopoly.

There are several interesting arguments that support the notion of a monopoly controlled telecommunication infrastructure. For example, rural areas typically encompass very low densities of customers for telecommunication services. As a result, Selwyn (1996, p. 87) argues, “economic efficiency is only possible if one provider has all of the customers in a rural market.” In addition, Caristi (2000, p. 24) notes that competitors duplicating hardware and software systems necessary to provide telecommunication service in larger markets are significantly less efficient than those able to provide service across a single system. Therefore, supporters of a monopoly-controlled markets argue that competitors constructing new systems for service provision create redundancy for which the consumer ultimately pays. In a non-monopolistic framework, ratepayers must subsidize multiple physical plants (Selwyn, 1996).

As Caristi (2000, p. 27) demonstrates, the combination of universal service, a natural monopoly, and the relative inefficiencies in serving rural areas created a system where a series of cross-subsidization plans were necessary for AT&T.

1. In order to reduce the costs of providing service to rural areas, AT&T used revenues generated in higher density urban markets to subsidize their rural customers.

2. AT&T charged a higher cost for long distance service to keep local service lower priced.

3. Businesses could be charged more for telephone services than residences.

With these types of cross-subsidization plans, it is obvious why the anti-competitive, natural monopoly was a necessity for AT&T. First, competitive carriers typically gravitate toward
the most profitable segments of the industry. In this case, the most profitable segments correspond to high-density urban markets. By choosing to serve only the densest markets, a competitive carrier can offer lower rates. In effect, the competition’s ability to offer lower rates squeezes AT&T out of the more lucrative urban markets and forces them to serve the less dense rural markets. For all intents and purposes, this cripples the utility of cross-subsidization plans and ultimately limits the effectiveness of the monopoly.

Aside from the complicated structure of cross subsidy plans, anti-monopolists note several problems with natural monopolies and the provision of telecommunication services (Egan, 1996). For example, Vogelsang and Mitchell (1997) suggest that monopolist views of rural customer densities do not consider the possibility of multiple-line users in businesses and apartment buildings. Also, rather than duplicating infrastructure, it is possible to lease lines from incumbent local exchange carriers to provide interconnection services.

After significant debate, anti-monopolist sentiment eventually prevailed in the United States and the telephone industry was deregulated with the passing of the Telecommunications Act of 1996 (TA96). TA96 seeks ways to secure lower prices and higher quality services for telecommunication systems in the United States without monopolies. Moreover, the TA96 encourages the rapid deployment of new telecommunications technologies. Also of significance is the opening of local loops for competition. A natural consequence of competition in the local loop is the reduction in costs for business telephone connections.

The Telecommunications Act of 1996 will have lasting effects on the provision of telecommunication services at a variety of scales. As mentioned previously, with local exchanges open for competition, business users benefit from lower priced services. However, the cross-subsidies that helped make rural access affordable are beginning to dry up. As a result, many states are beginning the regulatory reform process to keep the costs of telecommunication services under control (Duesterberg and Gordon, 1997).

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23 The local exchange loop refers to the physical connection from the subscriber’s premise to the carrier’s point of presence (Newton, 2000)
The TA96 also provides for the concept of universal service in the deregulated environment by creating the universal service fund (USF). Rather than cross-subsidies directly providing for low cost telecommunications service, the USF makes telecommunications providers apportion monies directly to a federal fund. Ultimately, the USF monies are allocated to provide affordable telecommunication service to schools, libraries, and health care centers under the E-Rate program (Caristi, 2000).

Even with the long history of striving for universal service through legislation, policy, monopolies, and competition, statistics indicate significant portions of the United States are without telecommunication services. For example, starting in 1995, the NTIA has surveyed and measured US household connectivity to the telecommunications and information infrastructure in the US. The surveys measure household telephone, computer, and Internet penetration rates across the United States in an effort to determine which households own telephones, personal computers, and access the Internet at home. Results indicate that penetration levels vary substantially. These penetration levels typically reflect differences in income, education, household type, and geography (NTIA, 1995).

A recent NTIA (1999) survey begins by examining telephone penetration rates. Today, telephones are classified as a “mature” technology. Simply put, telephones are common features in most American homes. Telephone penetration has stabilized at approximately 94% (NTIA 1999). However, there are significant disparities in telephone penetration between socioeconomic groups. For example, only 78.7% of households with incomes less than $5,000 have telephones, whereas 98.9% of the households with incomes over $75,000 have telephones (NTIA 1999). From a geographic perspective, there is relatively little disparity in telephone penetration by region. The Northeast, Midwest, South, and West all have penetration rates above 92%. However, there is significant variation in telephone penetrations within regions. For example, the state of New Mexico (grouped with Southern states in this study) has telephone penetration significantly below 90% (NTIA, 1999).
Not surprisingly, the state of Ohio also exhibits a fair amount of variation where telephone penetration is concerned. Figure 6.2 illustrates the percentage of households with no phones by local exchange. The most significant pockets of households with no phones are found in southeastern Ohio, roughly corresponding to the Ohio’s Appalachian counties. This is a very poor, rural, and economically stagnant region relative to other locations in the state. However, there are additional pockets of low telephone penetration outside of Ohio’s Appalachia, most notably in northeast Ohio. For example, the communities of Bloomfield, Mesopotamia, and Parkman, Ohio display very low penetration rates. In fact, these areas also correspond to Amish Mennonite settlements. The community of New Berlin displays the highest rate of non-telephone households at 50.15%.

Although telephone penetration rates remain excellent indicators of infrastructure availability and its subsequent use, telecommunication services are evolving. The NTIA survey questions regarding the Internet exemplify the breadth of telecommunication service now considered since the passage of the TA96. The Telecommunications Act of 1996 specifies that universal service be no longer confined to the traditional telephone service. As Mueller (1997) points out, the language in the Telecommunications act elucidates that universal service obligations must include the “evolving level of telecommunications services,” and the definition must take into account new advances in telecommunications and information technology (1997, 167).

6.1.2 Rural Economic Development and Telecommunication

The linkages between rural economic development and telecommunication have relatively short histories. For most of the 20 century, rural economies relied on natural resource-based industries such as mining, farming, and fishing to support the local economy (Adams and Stephens, 1991). However, the 1980s brought significant changes to rural communities throughout the United States. With downturns in the natural resource-based industries,  

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24 Local exchange polygons correspond to the geographic extent of a telephone exchange(s) service area.
Figure 6.2: Households with No Phones
increasing growth in the service sector, and significant reductions of intergovernmental transfers, rural economies became increasingly depressed. In addition, federal farm programs, a large source of income for rural areas also decreased during the 1980s (Adams and Stephens, 1991). Given the significant cuts in federal funding and assistance, rural communities were witness to dwindling tax bases and economic isolation.

To be sure, the concept of isolation is important when considering rural economic development. From a strictly geographic perspective, relative isolation from major urban centers certainly plays a role in terms of quality transportation infrastructure and the labor force. From a spatial-economic perspective, this relative isolation from urban centers also limits the possibilities for developing economies of scale for services and businesses because population densities are simply too low. As mentioned previously, a reliance on natural resource-based industries also left many rural communities with little diversity in their economic base. This general lack of economic diversity makes rural communities more prone to significant downward shifts than their urban counterparts when faced with a negative stimulus such as drought or a significant increase in the price of fuel.

The concept of relative isolation also plays a major role in the telecommunication infrastructure for rural areas. At the most basic level (telephone provision), the cost of building and maintaining the non-traffic sensitive components of telephone service is identical between rural and urban carriers. As Adams and Stephens (1991, p. 16) note, this portion of telephone service cost does not vary with volume. Consequently, with few subscribers in rural areas and large distances between them, physical plant costs per customer can be very high. There are additional complications in rural localities; these include the quality of copper lines and the type of switch installed at the local exchange. For example, local copper loops should be at least 24 gauge, insulated from electro-magnetic transmissions, and have limited contact to areas with high groundwater content. Wiring without these qualities significantly inhibits digital data transfer (Abe, 2000). This can have a marked impact when sending or receiving information over the Internet.

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25 Intergovernmental transfers include Social Security, Medicare/Medicaid, retirement, and disability programs.
with dial-up connections utilizing a telephone line. In addition, even relatively common technologies such as a fax machines are reliant on digital switches in the local exchange.

Today, telecommunication infrastructure comprises much more than the local copper loops utilized in analog telephone service. Fiber optic network backbones, network POPs, coaxial cable networks, and integrated digital switches are a small sample of the many infrastructure components found in communities today.

Therefore, in order for a rural community to maintain viability and attract economic development, there are several important issues that need to be addressed. Bernal et al. (1991) indicate that a community must be able to provide favorable transportation costs, a sufficient labor force, adequate infrastructure, and a good quality of life. Each portion of this development framework is discussed below.

6.1.3 Transportation

With the construction of the Interstate Highway system and a series of regional airports across the United States, transportation costs have decreased significantly over the past 50 years. As automotive and aircraft technologies improved, it became possible to ship and receive virtually anything overnight through companies such as Federal Express and United Parcel Service. However, there are still locations in the United States that do not benefit from extensive transportation infrastructure. For example, over 45% of Ohio’s counties do not contain any Interstate highway frontage. A significant number of these counties are located in Appalachian Ohio. Although interstate highways are not the only means of ground transit, the US Interstate system is certainly preferable to a state highway system. Given this fact, manufacturing based companies that transport source materials from multiple locations to a single plant can benefit from solid ground transport facilities.
6.1.4 Labor Force

The relative quality of a community's labor pool is also an important consideration for businesses looking to locate in rural areas. Many of the growing sectors in the economy associated with information technology require a well-educated workforce. As such, companies are looking to locate in rural locations that can provide such workers. Unfortunately, although a rural community might have a well educated labor pool, the number of available workers is often limited. As mentioned previously, low population densities negatively impact the profitability of telecommunication service in rural areas, and as illustrated here, negatively impact the availability of skilled workers (Bernal et al., 1991). Further, as Brown and Deavers (1991) note, the educational attainment in rural areas tends to be lower than nonrural areas. Empirical evidence also indicates that rural counties with higher percentages of high school graduates are less likely to remain economically distressed (Wood and Bischak, 2000).

6.1.5 Non-Telecom Infrastructure

As mentioned previously, transportation and communication infrastructure play an important role in making rural communities attractive to businesses. However, infrastructure extends well beyond roads and fiber optic cables. Basic city services such as fire and police protection are essential. Numerous counties in the state of Ohio completely lack 911 emergency service (Figure 6.3). Further, even if rural communities have an adequate infrastructure and a complete set of services, there is a potential for new businesses to overwhelm their limited capacity. As noted throughout this chapter, telecommunication capacity is questionable in many rural areas. As Bernal et al. (1991) suggest, in order to combat capacity issues in rural areas, firms might decide to completely bypass the local telephone company and build their own infrastructure. In fact, due to the telecommunication needs of many Wal-Mart stores and their
Figure 6.3: 911 Service in Ohio

Source: Public Utilities Commission of Ohio
propensity to locate in rural markets, the entire Walmart corporation operates on a VSAT network (Bernal et al., 1991).

6.2 Market Demand and xDSL Service

As illustrated in the previous section, telecommunication infrastructure is distributed rather unevenly between rural and urban areas for a variety of reasons. First, the historical legacy of the telecommunication system is that of a natural monopoly. Although universal service was an admirable goal, the only way for AT&T to serve rural areas was through a complicated mesh of cross-subsidies. Second, in the current era of deregulation, these cross-subsidies no longer exist. As a result, companies are free to serve the areas they deem most profitable. Initial empirical evidence suggests that urban areas are receiving the majority of telecommunication infrastructure investments. More specifically, the recent NTIA and RUS survey (2000) suggests that broadband services like xDSL are not widely available outside of urban areas. With that in mind, this section attempts to uncover additional empirical evidence regarding the disparities of xDSL infrastructure investment for the state of Ohio and to provide a basic explanatory framework (via logistic regression) supporting the identified patterns.

6.2.1 xDSL

One of the more heavily publicized modes of residential broadband Internet access in the telecommunication industry is digital subscriber line technology (DSL). Currently, there are several different versions of DSL available on the market. The most commonly available version for household Internet access is asymmetrical digital subscriber lines (ADSL), which allows for the overlay of a high capacity data channel on top of the standard analog voice channel through

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26 VSAT networks are used for satellite-based point-to-multipoint data communication applications. Contemporary systems can operate at 1.544 Mbps (Newton, 2000).
regular telephone lines\footnote{27} The \textit{asymmetric} portion of ADSL refers to the fact that downstream transmission to a home computer is higher than the return (upstream) channel speed. For example, a basic residential ADSL line can have 640k download and 90k upload speeds. Less common is the high-bit-rate version of DSL (HDSL). Deployment of HDSL requires two telephone lines, but produces speeds near T1 levels (1.5 Mbps). Finally, although very high speed DSL (VDSL) availability is limited to only a few cities in the United States, it offers the highest transmission speeds (nearly 50 Mbps). Unfortunately, VDSL access requires that customers be very close to the telephone company central office. Further, necessary equipment for VDSL is expensive, both for the consumer and the VDSL provider. As a group, the aforementioned technologies are referred to as \textit{xDSL}.

Although the convenience of receiving residential broadband access via telephone lines is promising, current \textit{xDSL} technologies are limited in geographic scope due to a variety of infrastructure requirements. \textit{xDSL} technology relies on copper based infrastructure set in place by telephone companies over the last 50+ years. At the heart of this infrastructure exists wire-centers and central switching offices (CO). "(w)ire-centers are the physical structures where the telephone company terminates subscriber outside cable plant (i.e. their local lines) with the necessary testing facilities to maintain them (Newton, 2000). In other words, these wire-centers serve as hubs for the local exchange. Central offices are buildings that contain the circuit switching equipment for all telephone lines serving a geographic area. This geographic area is commonly referred to as a "wire-center service area". Figure 6.4 illustrates the wire-center service areas for the entire state of Ohio. It is interesting to note that the geographic extent of wire-center service areas varies quite dramatically. In fact, there is a significant (yet moderate) negative correlation (-.322) between wire-center service area size and population density\footnote{28}. This suggests that as local population increases, wire-center size decreases. In other words,

\footnote{27} Standard telephone lines are constructed of two single core copper wires that are twisted around each other (twisted pair). In many homes, the copper wire dates back to the 1950s. This creates a very chaotic environment for \textit{xDSL} deployment due to the patchwork quality of the telecommunication infrastructure.

\footnote{28} Pearson's correlation coefficient; Significant at the 0.01 level
Figure 6.4: Wire-center Service Areas
telecommunication facilities in rural locations (lower population densities) typically serve larger geographic regions than those found in urban areas. As Egan (1996, 18) notes, “the average loop length for RUS telephone companies is 20,330 feet, which is significant considering that access lines longer than 18,000 feet usually require special treatment to insure high quality basic service.” This is an important observation for two reasons. First, this is more evidence suggesting the overall quality and density of telecommunication infrastructure is relatively lower in rural areas than urban areas. Second, there are additional aspects of xDSL service limiting the geographic extent of its reach.

Therefore, from a practical standpoint, the wire-center service area is the “trade area” corresponding to each central office. In other words, central offices act as service centers for all households in the wire-center service area. In fact, all telephone lines serving households located in a wire-center service area terminate at the CO. Considering that most xDSL equipment is placed in central offices for operation, each wire-center service area represents the potential xDSL market for providers. Consequently, companies looking to upgrade local infrastructure carefully examine the socioeconomic and demographic characteristics of the households each wire-center service area contains.

Reinforcing the relationship between wire-centers and xDSL providers is the cost of entry to a market. As Abe (2000) notes, COs are big, expensive buildings. Therefore, the construction of additional COs is not a trivial proposition. Rather than construct a new CO, competitive local exchange carriers looking to enter a new market typically rent space in existing COs from the incumbent local exchange carrier. This process is known as “co-location”. Moreover, because many xDSL providers are classified as competitive local exchange carriers, co-location is typically their only means for entering a market.

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29 This is discussed at length in the forthcoming Local Access Chapter
30 Recent technological advances in the local loop actually extend the reach of xDSL service. Next generation digital loop carriers utilize a hybrid transmission system (copper and optical fiber) to aggregate xDSL traffic from multiple premises, multiplex it (FDM or DSLAM) and send it back to the CO for eventual transmission to the commercial Internet (Newton, 2000). It should be noted, however, this type of local infrastructure is the exception, not the norm.
6.3 Methodology

Central office locations and their associated wire-center service areas are available from a variety of data vendors. Perhaps the most widely available data set on wire-center locations is the Local Exchange Routing Guide (LERG) available from Telcordia Technologies. These data contain information on the locations of central offices, the geographic extent of their coverage areas, and general information on CO capabilities for the United States. One of the biggest challenges in performing research in telecommunication is the relative timeliness of such data sources. As a result, many companies pay for monthly updates of the LERG database. More importantly, due to the competitive nature of telecommunication service provision, data sources documenting the locations of central offices actually offering xDSL service presents a challenge. The central office data utilized in this study were acquired from the Ohio Supercomputer Center via the Ecom-Ohio project. Portions of these data are provided by Cincinnati Bell, a corporate partner in the Ecom-Ohio project. The remaining data were acquired utilizing a “web spider”. This web spider iteratively searched a xDSL service clearinghouse, in order to ascertain which of the remaining central offices were equipped for xDSL service.

1997 Census estimates are utilized for evaluating the market characteristics for each wire-center service area. More specifically, Block group estimates of socioeconomic and demographic characteristics for the state of Ohio are aggregated to the wire-center service areas using Maptitude, a commercial geographic information system. Several dummy variables are incorporated into this study as measures of location and competition. One measure, accounting for the degree to which a wire-center service area is “urban”, is the MSA dummy. Therefore, all wire-center service areas within a county classified as an Ohio MSA are given a value of 1. A second dummy variable incorporated into this analysis is that of market competition from cable broadband providers. If a local cable franchise offers broadband Internet service in a community, this is considered a competitive threat to xDSL providers. It is hypothesized that well entrenched

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31 The quality of web-spidered data utilized in this study is very good. In fact, these data were cross-checked with matching records provided by Cincinnati Bell. In all cases, the web-spidered data and Cincinnati Bell’s locational information matched.
cable providers have a dominant market share. Therefore, market entry for xDSL providers becomes difficult, or at the very least, less profitable. As such, all wire-center service areas with cable broadband options are given a value of 1.

6.3.1 Limitations

To reiterate, the most significant limitation to this study is the evolving nature of residential broadband accessibility in Ohio. Local cable systems and xDSL providers are increasing their presence and capacity throughout Ohio on a daily basis. Therefore, the analysis presented in this section can only be viewed as a snapshot of xDSL accessibility. Second, the utilization of 1997 estimates certainly builds a small degree of error into the models. There is no doubt that the composition of Ohio's wire-center service areas have changed over the last three years. High growth areas represent the most significant problem in this analysis. For example, Delaware County (located north of Franklin County and Columbus) has an annual growth rate exceeding 15%. Common sense leads one to believe that this growth is spatially uneven. Therefore, the socioeconomic and demographic characteristics of high growth wire-center service areas are not reflected in the 1997 estimates or the logistic regression models that are to be used. Nevertheless, the 1997 estimates certainly provide an improvement over the use of 1990 data.

6.4 Results

6.4.1 Cartographic Analysis of Market Indicators

As history indicates, telecommunication providers obtain higher returns on their infrastructure investments in markets dense with customers (Caristi, 2000). Figure 6.5 illustrates household densities per square mile for each wire-center service area in the state of Ohio. In addition, each of the Ecom-Ohio study regions (NE, NW, SE, SW, Central, and Dayton) is illustrated. As expected, Figure 6.5 clearly exhibits the presence of higher household densities in major urban centers. Figure 6.5 also demonstrates the lack of a major urban center in the SE.
Figure 6.5: Household Density by Wire-center
It is important to note that the argument for density as it relates to telephone service is not directly comparable with density as it relates to broadband xDSL service. Although high household densities are positive characteristics for potential broadband markets, the households must also contain people interested in using high-speed Internet connections. As a result, xDSL providers are in search of wire-center service areas with dense populations of well-educated economically prosperous residents. In fact, the literature on Internet use suggests households displaying higher levels of both income and education are more inclined to use the Internet (Hoffman and Novak, 1999; NTIA, 1999). In addition, because xDSL is a premium service with installation charges approaching $300 and monthly service fees that range between $50 and $200, only a limited number of households can afford such service.

One measure of socioeconomic status is displayed in Figure 6.6; the percentage of households collecting public assistance in each wire-center service area. There are two patterns worth noting. First, many of the wire-center service areas located in major metropolitan areas display high percentages of households on public assistance. This trend is indicative of distressed inner-city neighborhoods, common throughout Ohio. One might hypothesize that these areas will not attract significant xDSL infrastructure investments. However, due to an increasing interest in affordable broadband access for small to medium sized businesses, one might suggest that inner-city neighborhoods (proximal to the CBD) represent a good market opportunity for xDSL providers. Second, southeastern Ohio displays remarkably high rates of households collecting public assistance across most areas. This clearly illustrates the depressed socioeconomic conditions of the SE region. Again, it is hypothesized that SE Ohio will not attract xDSL infrastructure due to such high rates of socioeconomic distress.

---

32 Installation and service fees can vary quite dramatically. Some companies offer a complete rebate on hardware and installation fees. Others still charge fees to account for the overhead associated with co-location. Many believe the RBOCs engage in predatory pricing as a means to eliminate competition (Kushnick, 2001; NewNetworks, 2001). Therefore, CLECs are frequently unable to offer competitive prices and installation rebates similar to the RBOCs.
Figure 6.6: Households Collecting Public Assistance by Wire-center
6.4.2 Broadband Provision

Given the spatial variation in market indicators illustrated in Figures 6.5 and 6.6, it is sensible to explore the spatial patterns of residential broadband provision for the state of Ohio to determine if these patterns visually correlate. Figure 6.7 illustrates locations where cable broadband services are available. It is clear that of the major metropolitan areas in the state have access to cable broadband. A variety of smaller communities also have access in NE Ohio. For example, Adelphia North Central Cable serves several cities south of the Canton MSA including Dover and Tuscarawas. The only cities with cable service in SE Ohio (Proctorville, and Southpoint) are served by Armstrong Southern and located in the Huntington, West Virginia MSA.

Although cable broadband access is clearly skewed toward the major urban complexes in Ohio, it is not exclusive to these areas. In fact, a variety of very small communities scattered throughout the Ecom-Ohio regions have cable broadband services. A more comprehensive listing of cable providers, the communities they serve, and the number of customers in their user base can be found in Appendix 1.

Figure 6.8 illustrates xDSL capable central offices and their associated wire-center service areas. In addition, Figure 6.8 also displays the percentage of non-telephone households by wire-center service area. As expected, xDSL providers have targeted major metropolitan areas for service. In fact, the majority of wire-center service areas in Cleveland, Columbus, Cincinnati, Toledo, and Dayton are xDSL capable. As hypothesized, there is a very low occurrence of xDSL enabled COs in service areas with high non-telephone households. The SE region of Ohio best illustrates this; only 6.4 % of the wire-center service areas in SE Ohio are xDSL capable.

Given the empirical evidence presented in this section, it is clear that the major urban areas in Ohio have a variety of choices for broadband Internet access. These results suggest that both cable and xDSL broadband options are widely available in the cities of Cleveland, Columbus, Cincinnati, Toledo, Dayton, and Akron. However, results indicate that a variety of
Figure 6.7: Cable Broadband Availability
Source: Ecom-Ohio
Figure 6.8: xDSL Enabled COs and Non Telephone Households
Source: Ecom-Ohio
smaller, rural communities scattered throughout the state also have broadband access options. This apparent diffusion of broadband access to more rural areas merits more extensive analysis.

6.4.3 Logistic Regression Analysis

Utilizing a binary dependent variable \( \begin{cases} 1 & \text{CO with DSL} \\ 0 & \text{CO w/o DSL} \end{cases} \), two logistic regression models were constructed to explain the market conditions indicative of residential xDSL service availability\(^{33}\). This approach is a means of testing the probability of a wire-center service area gaining xDSL service, or remaining service free, given a set of market conditions. For the purposes of analysis, variables with \( p \)-values less than 0.05 are considered significant contributors to a wire-center service area’s xDSL status. The independent variables included in the regression analyses were not randomly selected. As illustrated in sections 6.4.1 and 6.4.2, xDSL service appears to have a variety of interesting relationships between indicators of socioeconomic status and location. Table 6.1 outlines the variables used as market indicators for the regression models. Finally, all variables were screened using a scatterplot procedure to insure that collinearity was not a problem in the analysis. Variance inflation factors were also calculated.

6.4.4 Model 1

The first logistic regression model explores the relationship between xDSL service and the hypothesized “core” market indicators of household density, educational attainment, and income. Two dummy variables were also included in this model. First, the MSA dummy serves as a proxy for location and a relative measure of “urban” versus “rural”. Second, the cable competition variable is also included in Model 1.

As illustrated in Table 6.2, Model 1 displays a significant level of predictive ability. In fact, the overall prediction rate was 89.08%. Factors contributing to a xDSL enabled CO include

\(^{33}\) It is important to note the difference between residential and commercial broadband service provision for the purposes of this chapter. Rather than attempting to determine the market characteristics of commercial xDSL service provision, this chapter seeks to explain the presence of xDSL service as motivated by non-corporate entities (households). It is likely that the forces driving commercial and residential demand for xDSL broadband services are significantly different.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Status</th>
<th>Variable Description</th>
</tr>
</thead>
</table>
| Active   | Dependent | xDSL broadband availability by wire-center service area.  
|          |         | 0 = No Service; 1 = Service  
|          |         | Household density per square mile |
| HH97     | Independent | in wire-center service area.  
|          |         | Percentage of population w/ bachelors |
| BachGrad | Independent | or graduate degree |
| MedInc   | Independent | Median Income  
|          |         | Percentage of population collecting retirement income. |
| RetInc   | Independent | Wirecenter service area location:  
|          |         | Inside MSA County = 1;  
|          |         | Outside MSA County = 0 |
| MSA      | Dummy   | Cable Competition:  
|          |         | Inside wire-center = 1;  
|          |         | No competition = 0 |

Table 6.1: Variables Used for Logistic Regression
<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient Model 1</th>
<th>Wald Model 1</th>
<th>Significance Model 1</th>
<th>Coefficient Model 2</th>
<th>Wald Model 2</th>
<th>Significance Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-5.2645</td>
<td>66.2449</td>
<td>0.0000</td>
<td>-4.0548</td>
<td>20.7671</td>
<td>0.0000</td>
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<tr>
<td>HH97</td>
<td>0.0002</td>
<td>12.9345</td>
<td>0.0003</td>
<td>0.0002</td>
<td>16.0484</td>
<td>0.0001</td>
</tr>
<tr>
<td>BachGrad</td>
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<td>4.4151</td>
<td>0.0356</td>
<td>0.0002</td>
<td>3.4326</td>
<td>0.0401</td>
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<td>Comp</td>
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<td>0.1206</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>MedInc</td>
<td>3.61E-05</td>
<td>6.3265</td>
<td>0.0119</td>
<td>3.66E-05</td>
<td>6.4559</td>
<td>0.0111</td>
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<tr>
<td>MSA</td>
<td>0.8829</td>
<td>8.3726</td>
<td>0.0038</td>
<td>1.0049</td>
<td>1.0583</td>
<td>0.0012</td>
</tr>
<tr>
<td>RetInc</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-0.0718</td>
<td>4.0583</td>
<td>0.044</td>
</tr>
</tbody>
</table>

| Initial -2 Log Likelihood | 892.4263 | 892.4263 |
| Final - 2 Log Likelihood | 468.6380 | 466.8180 |
| Hosmer/Lemeshow Chi-Square [sig] | 11.2994 [.1853] | 10.3622 [.2405] |
| % Correct Predictions    | 89.08     | 89.43     |
| Nagelkerke - R^2         | 0.601     | 0.603     |

Table 6.2: Logistic Regression Results
higher household densities, higher educational attainment rates (bachelors or graduate degree), and higher median income levels. The MSA dummy variable is also a significant, positive factor in the model. This model suggests that xDSL providers are targeting upscale urban markets for service provision. The cable competition dummy was not found to be statistically significant in this model.

6.4.5 Model 2

The second regression model is a small deviation from the first. The core market indicators remain independent variables, however, an additional variable is incorporated into the analysis. The percentage of people collecting retirement income in each wire-center service area is included. It is hypothesized that service areas with higher percentages of retirees are less appealing to xDSL providers than service areas with a younger population. A second modification is the removal of the extraneous cable competition variable as it was determined to be insignificant in Model 1.

Before the results are discussed, it is important to examine model diagnostics to insure that the results are reliable. The initial log likelihood function, "-2 Log likelihood" (892.426) is indicative of the regression model accepting the null hypothesis that all the $b$ coefficients are 0. In other words, this function reflects the error associated with the model when only the intercept is included. The maximum likelihood estimation for Model 2 terminated at 5 iterations. The final log likelihood function "-2 Log likelihood" for this model is 466.818. As illustrated in Table 6.3, the model chi-square of 425.609 and a significance level of 0.00 indicate the model is indeed significant. In this case, the null hypothesis is rejected, indicating that none of the independents are linearly related to the log odds of the dependent. More importantly, with a chi-square of 10.3622 and a significance level of 0.2405, the Hosmer and Lemeshow goodness of fit test indicates statistically significant model estimates (Hair et al., 1999). Finally, the Nagelkerke $R^2$ is an attempt to provide a logistic analogy to the $R^2$ in ordinary least squares regression. In this case, a value of 0.603 indicates a good model fit.
The results of Model 2 indicate a slight increase in predictive capability (89.43%) when compared to Model 1 (89.08%). Household densities, educational attainment, income, and urban location remain important factors in predicting xDSL service. In addition, Model 2 determined the percentage of people collecting retirement income is significant ($p$-value = -0.0440). As hypothesized, this parameter had a negative impact ($R = -0.480$) of moderate magnitude ($Wald = 4.0583$) on the dependent variable.

There are several ways to assess the correct and incorrect predictions under logistic regression. A commonly used diagnostic for these purposes is known as a “classplot” (Figure 6.9). The X-axis is the predicted probability from 0.0 to 1.0 of the dependent variable being classified as “1” (xDSL enabled central office). The Y-axis is the frequency of classified cases. Inside the plot are columns of observed 1’s and 0’s with 10 cases per symbol. As Figure 6.9 illustrates, the model displays some bias in its estimation of xDSL enabled COs. For example, in difficult cases (near $p = 0.05$) the model tends to classify all COs as being xDSL enabled. In reality, this is probably a misclassification.

6.4.6 Residual Analysis

A second way to test the reliability and validity of a regression model is through the examination of residuals. The standardized residual values for Model 2 are linked to each wire-center service area in an effort to display how the regression model predicted xDSL service availability for Ohio (Figure 6.10). There are numerous interesting residual patterns evident in Figure 6.10. For example, several groups of wire-center service areas are present where Model 2 significantly underestimates the probability of xDSL service availability. Interestingly, several of these groups are located on the outskirts of Cleveland, Columbus, and Cincinnati. Table 6.3 displays the model results on a case-by-case basis for both overestimates and underestimates.
Observed Groups and Predicted Probabilities

Predicted Probability is of Membership for 1
The Cut Value is .50
Symbols: 0 – 0; 1 - 1
Each Symbol Represents 10 Cases.

Figure 6.9: Model 2 Classplot
Figure 6.10: Model 2 Residuals
<table>
<thead>
<tr>
<th>Underestimates</th>
<th>DSL</th>
<th>HH97</th>
<th>BachelorGrad**</th>
<th>MedInc</th>
<th>MSA</th>
<th>RetInc**</th>
<th>Predicted</th>
<th>Zresidual*</th>
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<td><strong>Akron/Cleveland Area (Medina)</strong></td>
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<td></td>
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<td></td>
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<td>Spencer</td>
<td>Y</td>
<td>23.82</td>
<td>5.57</td>
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<td>3.62917</td>
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<td>56.980</td>
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<td>Lodi</td>
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<td>14.933</td>
<td>0.13876</td>
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<td>8.78</td>
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<td>1</td>
<td>14.09</td>
<td>0.16327</td>
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<td>Sharon Center</td>
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<td>16.89</td>
<td>61.851</td>
<td>1</td>
<td>14.76</td>
<td>0.23262</td>
<td>1.94439</td>
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<td><strong>Columbus Area</strong></td>
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<td>New Albany</td>
<td>Y</td>
<td>73.47</td>
<td>19.22</td>
<td>59.804</td>
<td>1</td>
<td>18.94</td>
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<td>Lockbourne/Groveport</td>
<td>Y</td>
<td>189.51</td>
<td>6.7</td>
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<td>20.41</td>
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<td><strong>Cleveland Area</strong></td>
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<td>Independence</td>
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<td>14.67</td>
<td>53.517</td>
<td>1</td>
<td>29.83</td>
<td>0.26172</td>
<td>1.42219</td>
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<td><strong>Cincinnati Area</strong></td>
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<tr>
<td>Shandon</td>
<td>Y</td>
<td>69.01</td>
<td>8.85</td>
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<td>14.06</td>
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<td>Harrison</td>
<td>Y</td>
<td>162.78</td>
<td>8.86</td>
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<td>14.21</td>
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<td>Cleves</td>
<td>Y</td>
<td>96.55</td>
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<td>Batavia</td>
<td>Y</td>
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<td>8.07</td>
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<td>1</td>
<td>12.64</td>
<td>0.20851</td>
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<td>4.2</td>
<td>37.143</td>
<td>1</td>
<td>19.66</td>
<td>0.07116</td>
<td>3.77417</td>
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<td>Amelia</td>
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<td>36.889</td>
<td>1</td>
<td>14.74</td>
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<td>New Richmond</td>
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<td>7.54</td>
<td>42.997</td>
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<td>17.04</td>
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<td>17.78</td>
<td>0.13864</td>
<td>2.70048</td>
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<td>Lima</td>
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<td>242.73</td>
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<td>18.83</td>
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<td>Massillon</td>
<td>N</td>
<td>314.18</td>
<td>9.39</td>
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<td>13.13</td>
<td>0.90847</td>
<td>-2.68991</td>
</tr>
</tbody>
</table>

*Standardized Residual  **Values in Percent

Table 6.3: Model 2 Summary
6.4.7 Underestimates

Medina County

There are several service areas in Medina County (southwest of Cleveland) where the model significantly underestimates the probability of xDSL service. Underestimates refer to a positive residual between the actual and predicted values. From a geographic perspective, Medina County is one of the more interesting locations in Ohio. It shares borders with both Summit (Akron) and Cuyahoga (Cleveland) Counties, two of the largest population centers in the state. Given this intermediate location, Medina County is currently experiencing a period of significant growth. In fact, with easy access into downtown Cleveland via Interstate 71 and similar access into downtown Akron via Interstate 76, much of the residential development in Medina County is located in the bedroom communities of Brunswick, Wadsworth, Sharon Center, and Seville, Ohio. As a result, Model 2 underestimates in 60% of the wire-center service areas in Medina County. It is possible that the frequency of underestimates for xDSL enabled COs in Medina County stems from the 1997 census estimates not reflecting recent exurban growth. As a result, Model 2 is not able to pick up the increases in household density or rising socioeconomic status in these bedroom communities.

Other factors affecting the accuracy of Model 2 for this area might include the rapid commercial growth near the junction of I-71 and I-76 (Lodi, OH). More specifically, Model 2 does not include a mechanism that directly accounts for the presence of heavy commercial activity in wire-centers. As such, Model 2 does a relatively poor job of predicting demand by businesses for xDSL service. Therefore, the 80-store outlet mall managed by Prime Retail Outlets and the potential demand for broadband services that such a development might create are not accounted for.

New Albany

Similar to the bedroom communities of Medina County, the community of New Albany (NE of Columbus) is another very good example of an exurban community with recent rises in
aggregate population and socioeconomic status that has attracted xDSL infrastructure. Within a 30-minute drive-time of the Columbus CBD, New Albany is undergoing a period of significant, upscale, residential development. New Albany is also one of the most affluent communities in the Columbus MSA. In fact, the 1997 median income for this community is nearly $60,000. Again, the most recent residential growth is not accounted for by the 1997 estimates used in Model 2.

**Independence**

Another community where Model 2 under-estimates the probability of xDSL service is Independence, Ohio. Located on the Interstate 77 corridor south of Cleveland, Independence is a rapidly growing business center. In fact, the RockSide Road Business Park contains over 3 million square feet of office space for lease. In addition, as illustrated earlier in this chapter, Independence is home to several important points of presence (POPs) for commercial Internet backbones. With a rapidly expanding industrial and commercial base, southern Cuyahoga County and the community of Independence are prime targets for commercial xDSL service deployment. As such, the residential focus of Model 2 does a poor job of predicting xDSL service for this area.

**Lockbourne/Groveport**

Located south of Columbus, Lockbourne has a massive industrial base. One reason for such high levels of industrial and commercial development is the presence of Rickenbacker; a 5,000 acre cargo-dedicated international airport and foreign-trade zone. This area hosts over 50 distribution centers for major national and international corporations including; Xerox, Siemens, PetSmart, Kraft, and Kroger. Again, because of its emphasis on residential indicators of market demand for xDSL service, Model 2 is not able to identify the commercial and industrial base of Lockbourne as being indicators of demand for xDSL service.

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34 Household density remains relatively low when compared to similar communities. This might be a contributing factor to the under-prediction of New Albany in Model 2.
Figure 6.10 illustrates several groups of underestimated service areas located in the Cincinnati area (SW Ohio). With service areas in Ohio, Indiana, and Kentucky, Cincinnati Bell was one of the first telecommunication companies in the country to roll out xDSL service. In fact, Cincinnati Bell has anointed Cincinnati and its suburbs as “showcase” communities for its DSL services (Ecom-Ohio, 1999). As a result, 7\% of the businesses in SW Ohio use DSL service. Moreover, this 7\% penetration rate is much higher than any other region in the state and above the national average (Ecom-Ohio, 1999). Although Model 2 does an adequate job of predicting xDSL availability for the majority of Cincinnati’s central city, the less dense, more suburban locations in Clermont county and western Hamilton County proved more difficult to predict. Model 2 was not able to account for the aggressive nature of Cincinnati Bell and their xDSL service agenda.

Other Under-predictions

The remaining areas where Model 2 underestimated xDSL presence are primarily small to medium sized communities, many of which are relatively isolated from metropolitan statistical areas. For example, the city of Marysville, located in Central Ohio (NW of Columbus), has xDSL service available. Although Marysville is not a large city, one might argue that the presence of a Honda Motors manufacturing plant and its various support industries might raise the demand for a broadband service such as xDSL. Other communities under-predicted by Model 2 include Wapakoneta, Celina, Marion, and New Philadelphia.

6.4.8 Overestimates

Lima

There were very few instances where Model 2 significantly over-estimates the probability of xDSL service, however, there are a number of cases worth noting. Lima, Ohio, located in the NW region, is a medium sized city with a population of approximately 42,000. With a residual value of –3.83, Model 2 made a significant error in predicting Lima’s xDSL status. In reality, Lima
is a relatively depressed urban center. With unemployment rates above the state and national averages for 1998, demand for high-speed Internet service in Lima is probably lower than one might expect. However, empirical evidence indicates that Time-Warner Dayton provides cable-modem service to Lima and several surrounding communities. Given the aggressive nature of Time-Warner’s cable operations across the state of Ohio, especially in Columbus and Dayton, one might suggest their presence in Lima is a major factor contributing to the absence of a xDSL enabled CO.

Wapakoneta

Of additional interest in the Lima, Ohio MSA is the fact that Model 2 under-predicts for Wapakoneta, Ohio. As Figure 6.7 illustrates, Time-Warner Dayton does not provide cable broadband service for Auglaize County or Wapakoneta. However, as Figure 6.8 illustrates, xDSL services are available in the city of Wapakoneta. This suggests that a market for broadband services is present in the Lima MSA but the market’s two major centers (Wapakoneta and Lima) are accessing broadband through different platforms. This suggests that market penetration by xDSL providers can be influenced by the presence (or absence) of an entrenched cable broadband provider.

Massillon

Additional supporting evidence regarding the benefits of local entrenchment can be found in Massillon, Ohio. With a population of nearly 31,000 and a location in the Canton MSA, one might expect Massillon to have xDSL service available. However, similar to Lima, a very aggressive local cable provider serves the city of Massillon with broadband access. As a result, Massillon Cable makes market penetration for xDSL providers very difficult because they are so well entrenched in the market. With over 4,000 subscribers and 1,100 miles of infrastructure, Massillon Cable serves virtually every community west of Interstate 77 including the city of Wooster.
Another community that Model 2 over-predicted is Mason, Ohio. Located northeast of Cincinnati in Warren County, one would expect this growing city of 20,000 to have xDSL services available. With a little digging, it was determined that Mason’s central office is owned and operated by United Telephone Company of Ohio, not Cincinnati Bell. United Telephone of Ohio is a local subsidiary of Sprint and has a major presence across the state of Ohio where it owns and operates 20% of the COs. 100% of United Telephone central offices are without xDSL service. At the very least, these results alert one to the uneven nature of infrastructure upgrades by telephone companies across the state. It also alerts one to the fact that Cincinnati Bell is a very aggressive xDSL provider when compared to other telephone companies in Ohio.

6.4.9 Model 2 Discussion and Conclusions

As hypothesized, household density, income, education, and location play an important role in spurring the provision or residential xDSL service within Ohio. Model 2 also indicates that wire-center service areas with higher percentages of retirees are less likely to obtain xDSL service than those with a younger populace. Therefore, although Model 2 does a very good job of predicting residential xDSL service for Ohio, it is clear there are several trends prevalent in many communities that the Model 2 is not accounting for.

First, Model 2 does not account for any factors that might contribute to upgrades in CO infrastructure (xDSL) for the purpose of serving commercial entities. In other words, Model 2 fails to incorporate proxies for market demand stemming from the commercial side of broadband service provision. As a result, the model expected a low probability of xDSL active central offices, when in fact, several high intensity commercial wire-centers such as Independence, Lockbourne, and Lodi have xDSL equipped COs.

Second, although a cable competition variable was utilized in Model 1, it was determined to be statistically insignificant. However, as the analysis of residuals for Model 2 indicates, competition from cable providers can have an influence on the market locations where xDSL
providers decide to upgrade infrastructure. As illustrated in the previous discussion, both
Massillon and Lima are good examples of communities where a cable provider has acquired a
dominant market share in the provision of residential broadband services. This type of
entrenchment by cable providers can certainly limit the appeal of entering a market for xDSL
providers. Therefore, one might suggest that the varieties of broadband platforms available in a
city are somewhat related to the size of a city. In the case of xDSL and cable, both platforms are
widely available in Ohio’s major urban centers. However, smaller urban centers such as
Massillon and Lima appear prone to market dominance by a particular platform, in this case, cable.

Third, contrasting both Massillon and Lima is the city of Cincinnati, where several
broadband platforms are available. In addition to Cincinnati Bell xDSL services, Time-Warner
Communications has made RoadRunner cable broadband available to most of Cincinnati and its
first ring suburbs such as Lynchburg and Springfield (Appendix 1). However, empirical evidence
indicates Cincinnati Bell’s xDSL service completely dominates the outlying communities of
Cincinnati and SW Ohio, particularly Clermont County and western Hamilton County. In this
sense, one might suggest that Cincinnati Bell is very similar to the cable providers in Massillon
and Lima. It has acquired a dominant share of the broadband market, making these smaller
(lower density) communities less appealing to cable broadband providers.

Finally, results suggest that newly developing exurban bedroom communities can attract
xDSL infrastructure investment. In its current state, Model 2 does not accurately predict xDSL
service availability in communities such as New Albany, Brunswick, Wadsworth, and Sharon
Center. However, as mentioned earlier, results suggest that this is simply a function of the
currency of socioeconomic data utilized for analysis35.

As illustrated by points two and three, institutional factors clearly play a major role in the
provision of telecommunication services. Although Cincinnati Bell has done a remarkable job in
rolling out their DSL products, the Ameritech service region, including the state of Ohio, has been

35 1997 estimates are the most current data available at the block group level.
plagued with problems in the provision of both basic telephone service and DSL broadband. For example, in June, 2000, the Public Utilities Commission of Ohio ordered Ameritech to spend $8.7 million to improve customer service or it would face another $122 million in fines. This announcement was based on Ameritech’s slow installation service, missed installation or repair appointments, and the improper and frequent use of the “act of god” exception, claiming weather-related delays in service (AP, 2000). Where xDSL service is concerned, Ohio has benefited from the acquisition of Ameritech by SBC. With the launch of “Project Pronto”, a $6 billion dollar initiative, SBC made xDSL their premier platform for residential broadband, seeking to connect 77 million Americans in their service area (SBC, 1999). Even with initiatives like Project Pronto, it is clear that the Bell telephone companies are still very protective of their old monopoly markets, especially where competitive local exchange carriers are concerned (Kushnick, 2000). A more thorough discussion of competition in the local loop and predatory pricing, especially in the context of broadband provision is provided in Chapter 7.

As telecommunication companies continue to upgrade local infrastructure (cable or xDSL) the ability to access high-speed connections will improve for many. Moreover, the choices for residential broadband are continually expanding. For example, although this section stresses the availability of cable and xDSL, wireless broadband is also becoming available in many cities around the United States. All things considered, cable, xDSL and wireless technologies hold much promise for helping close the digital divide in the long term. In their current state, however, these technologies are not widely available in all areas. As mentioned in Section 6.1, the intent of the Telecommunications Act of 1996 was to open the market for competition, insure competitive pricing, and increase quality of service. The results of Section 6.4 indicate the TA96 is not benefiting all areas equally. Results support previous empirical findings that suggest that rural areas are severely lagging behind urban centers where telecommunication access is concerned. Moreover, much of this inequity in service can be attributed to telecommunication providers ignoring “costly” rural markets and providing service to the most lucrative urban sectors. Therefore, the problem of rural broadband access continues to be of great concern.
6.5. Rural Telecommunication Initiatives

Issues pertaining to rural broadband access and the acquisition of telecommunication infrastructure are well understood at the federal, regional, and local levels. As a result, many initiatives are taking shape across these rural locales to insure infrastructure upgrades of some form. At the federal level, the Rural Services Utilities branch of the United States Department of Agriculture is currently providing $100 million in treasury rate loan funds to encourage telecommunications carriers to provide broadband service to rural consumers where such service does not currently exist (USDA, 2000). However, waiting for national telecommunication firms such as Qwest, MCI, or AT&T to provide infrastructure improvements through such federal programs can become an exercise in futility for many rural locales. As a result, many communities are taking matters into their own hands.

This section provides two snapshots of rural telecommunication initiatives in the United States. The first community to be analyzed is La Grande, Oregon. La Grande’s struggle to gain a point of presence (POP) was documented in a series of reports by the San Jose Mercury News that examined the challenges of “wiring” the rural west (Plotnikoff, 2000). The second city to be analyzed is Marietta, Ohio. Located in Ohio’s Appalachia along the Ohio River, Marietta is a rural community that finds itself hard-pressed to gain residential broadband access because of its location. Although the motivation for increased telecommunication infrastructure in these two cities is different, both efforts represent interesting combinations of public-private cooperatives and forward thinking public policy.

6.5.1 La Grande, Oregon

Technological change has always fascinated scholars. Over thirteen years ago, Pascal proclaimed, “(t)ecnological change ramifies through societies, altering economies and thereby diffusing the interactions in space. What once had to happen in the city can now take place anywhere” (Pascal 1987; 597-603). Although Pascal’s view on technology is quite liberal,
Internet technologies can make rural locations less isolated through their ability to facilitate communication.

Under this framework, La Grande, Oregon is one of the many rural communities positioned to benefit from telecommunication technologies like the Internet. Similar to other small towns in the rural west, La Grande (pop. 13,000) is hundreds of miles from the nearest major population center, with the Willamette Valley and the city of Portland being 250 miles west of La Grande. The Cascade Mountains of Oregon and Washington act as physical, cultural, and economic barriers between the western and eastern portions of these states. In both cases, population settlement on the eastern side of the Cascades is sparse. In fact, although Eastern Oregon accounts for over 50% of the state landmass, it accounts for only 5% of the population (170,000). Moreover, the reason La Grande provides such an interesting study in telecommunication infrastructure development stems from its relatively isolated location in Eastern Oregon.

Similar to other rural regions such as Appalachia and the Great Plains, Eastern Oregon’s economic base has traditionally relied upon natural resource-based industries such as mining, farming, and ranching. This type of economic base is in direct contrast to the major urban centers of Western Oregon. For example, Portland is home to more than 1,200 technology companies including Intel; the largest private sector employer with 11,000 workers, to Hewlett-Packard, Epson, NEC and scores of small software firms. Because of this emphasis on technology, empirical results from Chapters 3 and 4 indicate that Portland has one of the best telecommunication infrastructures in the United States.

It should be no surprise, therefore, that communities like La Grande are unwilling victims to the technological dominance of Portland and the Willamette Valley. Because of market opportunities in the larger population centers like Portland, Salem, and Eugene, rural communities in Eastern Oregon are largely devoid of telecommunication infrastructure. More importantly, La Grande’s relative isolation from population centers also makes economic
development more of a challenge. As Plotnikoff (2000) notes, it was the promise of jobs that sparked La Grande’s interest in expanding the city’s telecommunication infrastructure in 1995.

Sykes Enterprises is a large international corporation that provides technological support in a variety of sectors including telecommunications, financial services, and retail. In 1995 a representative for Sykes was scouting potential locations for a call center and arrived in La Grande. This in itself is not a surprise; telemarketing firms and “back office” operations frequently locate throughout rural areas in the United States (Strover and Williams, 1991). As Bernal et al. (1991) note, rural areas typically provide a cheap labor force and a strong work ethic. Moreover, as metropolitan labor markets become increasingly tight, corporations are targeting smaller communities with a relatively high pool of available workers for establishing technical support centers (Plotnikoff, 2000). Given these criteria, the presence of Eastern Oregon State College, and easy access to Interstate 84, the community of La Grande appeared to be a good fit for a technical support facility in 1995.

However, in order to attract a Sykes technical support facility, La Grande needed a fiber optic point of presence (POP). Broadly defined, a point of presence is a physical location where a carrier (Internet service provider) has a presence for network access. This usually takes the form of a switch or router that allows local, regional, or national traffic to gain entry, or continue its journey on commercial Internet backbones (Newton, 2000). As illustrated in previous chapters, POPs are not evenly distributed across the United States. In fact, major metropolitan areas such as Portland tend to dominate this portion of the Internet infrastructure, thereby acting as peering points for commercial backbone providers. Needless to say, the lack of a POP in La Grande spurred Sykes to locate in a different city.

Efforts to attract infrastructure upgrades began in earnest after Sykes located elsewhere. As mentioned previously, the city of La Grande is located adjacent to Interstate 84. In fact, I-84 is the only major Interstate located between Oregon and Idaho. As Moss and Townsend (2000) suggest, Internet backbones often “traverse private and public rights-of-way, often alongside highways or railroad lines, to connect metropolitan areas across the country.” Therefore, La
Grande’s location afforded additional hope for attracting an infrastructure upgrade. In fact, as Plotnikoff (2000) notes, three months after Sykes pulled out, the community leaders of La Grande learned that WorldCom was about to run a new segment of fiber optic cable along I-84. In an effort to assert the community's interest in a POP, La Grande's leaders attempted to restrict the deployment of the fiber optic line by maintaining the county needed to issue a conditional-use permit before any building could take place; in effect, without a POP, no conditional-use permit. Once again, La Grande was denied improvements in infrastructure. As Plotnikoff (2000) notes, the right to regulate the building of telecommunication lines or fiber optic cables sits with the federal government, not local jurisdictions. WorldCom eventually built the fiber optic line along I-84, but without a POP in La Grande.

In September of 1999, La Grande finally acquired an active POP. ODS Health Plans, a major insurer from Portland, decided La Grande was an excellent community to locate a call center and claims processing facility (Plotnikoff, 2000). Again, significant amounts of bandwidth were required to maintain communication between the home office in Portland and its call center in La Grande. After a near disaster with lack of capacity on a digital microwave link, Touch America established a new interconnection point in La Grande by utilizing an AT&T fiber optic cable, which had been buried (and forgotten about) since 1988 (Plotnikoff, 2000).

As this case study illustrates, the promise of 50 jobs for a rural community like La Grande generates a great deal of interest. More importantly, La Grande’s ordeal in attempting to acquire an upgrade in telecommunications infrastructure helped spur the development of the Oregon state Senate Bill 622. This legislation provides for the creation of Telecommunications Infrastructure Accounts (TIA) by carriers that opt for “price-cap regulation”. In effect, price-cap regulation is an alternative to “rate of return regulation” that establishes price ceilings and price floors on rates for basic services. This allows for greater profit margins for carriers that opt into this framework. As a result, participants such as US West (now Qwest) commit 20% of their prior year gross regulated intrastate revenue to the TIA over a period of four years (2000 – 2004) (OECDD, 2000). Estimates indicate Qwest will deposit up to $120 million into the TIA alone.
Needless to say, this has spurred an unprecedented era of telecommunication infrastructure growth throughout the state of Oregon. More importantly, these developments represent an interesting policy based model for rural infrastructure development.

6.5.2 Marietta, Ohio

Marietta, Ohio (pop. 14,500) shares many similarities with La Grande, Oregon. Both communities are relatively isolated from major urban centers; Marietta is 170 miles from Cleveland, 130 miles from Columbus, and almost 90 miles from the West Virginia state capitol of Charleston. Similar to La Grande, Marietta is also home to a small college (Marietta College) and is located in a relatively depressed county (Washington) with unemployment rates exceeding state and national averages.

As illustrated in Section 6.3, telecommunication infrastructure is almost completely absent in Ohio’s Appalachian counties. In fact, Washington County is one of the locations identified by the Public Utilities Commission of Ohio that lacks 911 emergency services. Cable and xDSL broadband options are also missing from the greater Marietta area. Much of this “underdevelopment” stems from low population densities and the lack of interest in such markets by telecommunication providers. However, rather than wait for infrastructure development that might never materialize, the residents of Marietta decided to take matters into their own hands.

After conducting an eighteen-month study, community officials determined that the commercial, educational, and medical sectors of the local economy desperately needed broadband Internet access. The president of the CIC believes that several large chemical companies (Shell and DuPont) might be forced to leave the area without adequate access to broadband services (Rieser, 2000). As a result, the city of Marietta and Washington County are utilizing the Washington County Community Improvement Corporation (CIC), a 37 year old non-profit, to sponsor a non-profit corporation called Sequelle in developing a high-speed wireless broadband network (Govtech, 2000).
One might question the use of wireless technology for broadband access considering that this method of implementation is largely missing from most major metropolitan areas. Proponents in Washington County argue that even though fiber backbones provide high quality service, they are not cost effective. With costs exceeding $20,000 per mile, fiber is the appropriate choice in linking population centers. In effect, the higher densities of these areas allow for economies of scale to develop. As such, the costs of fiber connections are offset by intensive use. However, given Marietta’s location on the Ohio River, and the complex topography of the Ohio River Valley, fiber installation for Washington County and surrounding areas has the potential to increase by a factor of ten (Sequelle, 2000) due to the lack of easy right-of-way. As a result, the CIC and Sequelle determined that wireless broadband is the best solution for the area.

As expected, the technical considerations for such a broadband network are complicated. For example, in most major urban areas, cellular networks are rapidly accumulating the remaining protected and licensed bandwidth for their digital services. Therefore, due to the explosion of cellular phone usage and wireless messaging, the wireless options for broadband networks in these areas are very slim; especially on FCC administered frequencies. However, isolated rural communities, removed from population centers like Columbus, are not facing the same problems of shrinking frequency options. Sequelle plans to utilize a two-way digital radio frequency that is licensed by the FCC to Mountain State College in Parkersburg, West Virginia for their broadband services. Originally allocated by the FCC to Mountain State College as a means to facilitate educational and commercial partnering via television, the FCC recently granted permission to switch them from analog to digital (Rieser, 2000).

Current funding estimates for this project exceed $3 million. Funding is expected from a combination of federal and state monies with the majority coming from the Ohio Department of Development (Rieser, 2000). In addition, the Ohio Department of Jobs and Family Services has already provided $130,000 for organizational startup (Rieser, 2000).

Although the final product is more than one year away (2002), it is clear that the efforts of Marietta, Washington County, and the CIC provide an innovative framework for rural
telecommunication infrastructure development. Perhaps most uncertain is the degree to which the wireless broadband network will spur economic development for the region. Although Sequelle estimates 300 users by the end of the third year, it is not clear who will be using the service. At the very least, Sequelle itself will provide 48 full time jobs for the area.

6.5.3 Discussion

Telecommunication development is frequently touted as a cure-all to the economic woes of Rural America. However, as Korsching et al. (2000, p. 278) suggest, although technological infrastructure supports services such as the Internet, it is certainly not sufficient for rural economic viability. As exemplified by the case studies of La Grande and Marietta, initial efforts yielded good short-term results; in both cases, approximately 50 new jobs were generated. However, the long-term economic prospects for these cities and others like them remain unclear. Fourteen years ago, Tweeten (1987) suggested that the impact of telecommunications on rural areas would be minimal. Although businesses are attracted to the prospects of low wages and reduced taxes in rural areas, high technology firms are more attracted to urban areas where large pools of technically skilled workers are available (Tweeten, 1987).

Where the rural areas of Ohio are concerned, all is not lost. In addition to the local initiative in Marietta, several imaginative organizations are looking to increase SE Ohio’s prospects for economic development. The Appalachian Center for Economic Networks (AceNet) is one such organization. Through the support of the Appalachian Regional Commission, AceNet attempts to assist businesses with start up or expansion needs in the specialty food and technology sectors. In effect, AceNet is a small business incubator for this sector. In addition, a joint effort between AceNet and Ohio University seeks to develop a strategy to expand technology in the region by providing technical and support services and capital through the AceNet Ventures Fund. In fact, AceNet estimates that within the next five years the fund will “complete 180 investments, enabling 50 firms to move from a half million to $5 million in sales,
and another 50 to grow substantially but less rapidly thereby creating more than 1,500 new, high-quality jobs in SE Ohio” (AceNet, 2000).

6.6 Summary

This chapter attempted to illustrate the marked disparities in the presence of telecommunication infrastructure between rural and urban areas in the state of Ohio. Empirical evidence suggests that federal policy, specifically the Telecommunications Act of 1996, has a significant impact on the location of infrastructure investments. As such, urban areas such as Cleveland, Columbus, Cincinnati, Dayton, Akron, and Toledo display dominant shares of both cable and xDSL broadband infrastructure. The explanatory framework presented in this chapter suggests that household density, income, education, age, and competition play important roles in determining which locations telecommunication companies decide to upgrade infrastructure.

In addition, this chapter also attempted to highlight many of the prospects for rural economic development enabled by telecommunication infrastructure upgrades. As the case studies of La Grande and Marietta suggest, although telecommunication is an important part of the development equation, other factors, including transportation infrastructure and the quality of the local labor force certainly factor into economic viability.

The last major conclusion offered in this chapter is this; the digital divide encompasses significantly more than the differences in socioeconomic standing and demographic make-up of a community. In fact, this chapter illustrates a very strong spatial component to Internet access. In effect, where one lives often dictates the level of access one has to the Internet or other telecommunication technologies. The next chapter will explore the sub-metropolitan aspects of xDSL access for the city of Columbus.
The previous chapter illustrated the spatial disparities in xDSL enabled central offices in the state of Ohio. In this chapter, the impact of local geography on broadband xDSL network access will be examined more closely. Specifically, household and business proximity to a central telephone switching office (CO) is evaluated. This type of micro-geographic analysis is important in two ways. First, a detailed analysis at the local level has the ability to reveal spatial disparities in infrastructure access that many studies have suggested exist (NTIA 1995, 1998, 1999), but evidence is generally quite sparse. Second, because broadband access is quickly emerging as the technology of choice for both small businesses and households (Clarke et al. 1998), it is important to consider which locations will have opportunities for these connections and which locations will not. Further, although the “digital-divide” is frequently conceptualized through the analyses of demographic and socioeconomic status, there is the possibility that a new divide is forming at the local level which is based on the goals of profit-seeking firms and the physical architecture of the Internet.

The next section provides pertinent background information on broadband technologies with a special emphasis on xDSL, xDSL providers, and the characteristics of local Internet architecture that affect transmission speed and quality. This is followed by details regarding the structure of the application study. Results will then be presented. Finally, a discussion and conclusions are given.

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36 A modified version of this chapter will be published in Papers in Regional Science, coauthored with Alan T. Murray.
7.1 The Digital Divide and Broadband Access

As mentioned throughout this thesis, inequities in Internet availability and service are broadly categorized under the term “digital divide”. Numerous studies document the disparate rates of Internet use and computer ownership in the United States. The most recent statistics indicate that 51% of U.S. households own a computer while 41.5% have access to the Internet (NTIA, 2000). According to NTIA (2000), the 51% computer ownership rate reflects an increase of 56% between 1998 and 2000. Although computer ownership and Internet access rates are increasing in the United States, these statistics suggest universal service for the Internet is far from realized.

One rapidly growing segment of the telecommunication industry is “residential broadband”. This refers to a series of network technologies that promise to deliver high-speed network access to homes and small businesses. By definition, the Federal Communications Commission defines broadband as the capability of supporting at least 200 Kbps in the consumer’s connection to the network, both from the provider to the consumer (downstream) and from the consumer to the provider (upstream) (NTIA, 2000). Unlike traditional dial-up services, which operate between 28.8 Kbps and 56 Kbps, residential broadband offers significant improvements in transmission speed.

Broadband is also steadily gaining support as a means to eliminate existing barriers to Internet usage. In 1998, the Aspen Institute held its 13th Annual Conference on Telecommunications Policy. The focus of the conference centered on issues of residential access to bandwidth and the overall quality of available service. The conference panels cited two major steps to insure the diffusion of Internet access (Entman, 1999). First, most panelists believed that residential broadband service was a desirable and attainable goal. However, they specified a need to develop a new regulatory framework to insure that access be deployed efficiently and in an equitable manner. Second, if inequities are found during residential
broadband deployment, a subsidy program would be a logical next step toward the reduction of these inequities (Entman, 1999).

There are additional issues regarding the provision of residential broadband services that are of great consequence. In a recently issued report by the National Telecommunications and Information Administration (NTIA), evidence suggests that rural areas are currently lagging far behind urban areas in broadband availability (NTIA, 2000). In fact, although cable modem and xDSL technologies are making residential broadband a reality, infrastructure investments for these technologies are primarily found in urban and suburban markets. For example, 65% of the cities surveyed in the NTIA study with populations over 250,000 have both cable modem and xDSL service. However, only 5% of the cities with populations under 10,000 have cable modem service or xDSL service (NTIA 2000). Additional evidence is provided in Chapter 6, where southeast Ohio is shown to have very few opportunities for either xDSL or cable model broadband service. This relative scarcity of residential broadband availability in rural areas suggests that the “digital divide” is present in the United States.

7.2 xDSL

As outlined in Chapter 6 (Section 6.2.1), one of the more popular platforms for broadband access is digital subscriber line technology (DSL). Currently, there are several different versions of DSL available on the market. Available in a variety types (HDSL, VDSL, ADSL) and speeds, the most commonly available version for household Internet access is asymmetrical digital subscriber lines (ADSL). As mentioned previously, the asymmetric portion of ADSL refers to the fact that downstream transmission to a home computer is higher than the return (upstream) channel speed.

7.2.1 Infrastructure Requirements

Although Chapter 6 outlined many of the infrastructure requirements for xDSL service, it is worthwhile to reiterate the geographic limitations of xDSL service by revisiting several key
requirements and introducing several more. xDSL is a copper based technology that utilizes a central switching office (CO) or “wire-center” to supply xDSL service to both households and businesses in a geographic area. This geographic area is commonly referred to as a “wire-center service area”. All telephone lines serving homes or businesses located in any given wire-center service area terminate at the CO. As mentioned in Chapter 6, the wire-center service area is effectively the “trade area” for the COs.

To this point, the role of copper infrastructure and its ability to transmit digital data at high bandwidths has not been addressed. In the strictest sense, copper is not the best material for this. National Internet backbones rely on fiber optic cable that supplies both high capacity and high quality. Where xDSL is concerned, significant technological advances are allowing copper transmission systems to expand beyond the 4 kHz bandwidth capacity used for analog phone transmissions. More specifically, the multiplexing technology in xDSL allows advanced line coding algorithms to divide the spectrum on copper phone wires (twisted pairs) between voice and data. Figure 7.1 illustrates this increased frequency range. In addition to allowing standard voice transmissions at 4kHz, xDSL technology extends the range of data transmission frequencies (both upstream and downstream) to 2.2 MHz (lms et al., 1998). In other words, both voice and data are transmitted simultaneously over the same copper wires. Even given the above noted sophistication, there are limitations to copper transmission systems. Primary challenges include crosstalk and signal degradation. Secondary challenges to xDSL access include the use of digital loop carriers, load coils, and bridge taps.

Perhaps the biggest limitation to xDSL technology is the distance requirement from a household to its central office. As mentioned earlier, this spatial limitation can be explained by the inability of copper transmission systems to transmit high frequencies over extended distances. Figure 7.2 illustrates the spatial limitations of xDSL service in relation to central office and subscriber location. As indicated in Figure 2, the maximum coverage radius for xDSL is approximately 18,000 ft. This means that if a potential subscriber location is further than 18,000 ft. from its CO, there is generally no opportunity for xDSL service. Further, these distance
Power or Amplitude

Figure 7.1: xDSL Bandwidth Frequency
Figure 7.2: xDSL Range from Central Office

<table>
<thead>
<tr>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5000 ft.</td>
<td>A) No problem in receiving high quality xDSL service.</td>
</tr>
<tr>
<td>5000-11000 ft.</td>
<td>B) xDSL is available, but the highest transmission speeds may not be.</td>
</tr>
<tr>
<td>11000-15000 ft.</td>
<td>C) Speeds are limited, and some national carriers may refuse an order.</td>
</tr>
<tr>
<td>15000-18000 ft.</td>
<td>D) Some versions of xDSL may be available, but speeds are severely restricted (300k - 500k).</td>
</tr>
<tr>
<td>&gt; 18000 ft.</td>
<td>E) Generally, xDSL is unavailable.</td>
</tr>
</tbody>
</table>
measurements represent a “best case” scenario where copper wiring is at least 24 gauge, insulated from electro-magnetic transmissions, and has limited contact to areas with high groundwater content. In fact, many xDSL providers are hesitant to establish residential service unless a household is within 12,000 ft. of a CO, as indicated in Figure 7.2, because the aforementioned limitations tend to increase in frequency with distance (DSLreports, 2000; COVAD, 2000; Telocity, 2000).

In addition to the spatial limitations of xDSL service, there are other equipment and infrastructure hindrances that exist which affect the availability and quality of xDSL service throughout the United States. For example, digital loop carriers consolidate voice traffic of remotely located customers onto a few copper transmission cables that run back to the central office. This process allows telephone companies to serve their overload subscribers in a given area without increasing the number of physical lines. Although analog transmission quality suffers very little, traditional digital loop carrier systems cannot support the amount of bandwidth necessary for the digital transmissions of xDSL. Load coils are passive (unpowered) devices that lengthen the distance voice can travel over phone wire. Usually, they are placed on the local loop (the line between a household and CO) in 3,000 – 6,000 ft. intervals to increase the overall fidelity of a voice signal. Without load coils, the original analog voice signal becomes crippled by its own reflection in the copper wires (Cartwright, 2000; Abe, 2000). Moreover, because load coils are suppressing noise at high bandwidth, the net effect on xDSL is a very negative one. Finally, bridge taps are “accidental” connections of an additional local loop to the primary local loop. There are millions of bridge taps located in residential areas and business parks throughout the US. When a phone company runs copper cable down a residential street, the length of the cable serving any given household often extends well beyond the residence it serves. In other words, the installer has more cable than needed. Instead of cutting that cable, installation technicians often leave the extra length in case they have to use it for another household later. Installers are then able to take the wires from the household in question and tap (via splice boxes) the main copper cable serving a residential street, subsequently running back to the CO. The extra wiring
left in place during installation can severely impede xDSL transmission quality to a household (Abe, 2000).

7.2.2 Deployment

As with their colleagues in the dial-up (≤ 56k) Internet Service Provider market, there is no mandate providing for the equitable distribution of xDSL service. Commercial Internet service providers are free to choose their operating areas and subsequent geographic coverages based on market demand. With respect to the commercial Internet service provider market, Downes and Greenstein (1998) note:

1) The diffusion of Internet access is a market and profit driven process. As such, the development of access in high-density population centers has preceded that of rural locales.

2) Some markets are competitive while others are not. Residents of urban areas typically have multiple choices for providers, while residents of rural areas do not (this can affect price structures and quality of access).

3) The market structure for Internet access can vary widely. Rural areas are largely covered by local or regional Internet service providers while a mix of national, regional, and local providers cover urban areas.

Many of the same market forces apply to the commercial xDSL market. Currently, there are two different parties competing for the same pool of xDSL dollars; regional Bell operating carriers (RBOC) and competitive local exchange carriers (CLEC). As mentioned previously, RBOCs such as Verizon and SBC own the copper infrastructure and COs for most of their service areas. As Kushnick (2001) notes, many believe that the RBOCs are still monopolies, utilizing their control on the infrastructure to kill xDSL broadband competition by complicating the installation of xDSL services and inhibiting access to the copper infrastructure for CLECs. There are additional factors that affect xDSL rollout by commercial providers. First, the digital switching
equipment is very expensive. Commercial providers such as COVAD and Telco must make carefıl decisions on the locat ons that such equipment is placed. This suggests that, although xDSL service is available in a city, portions of that city will not be covered because the necessary digital switching equipment is not likely to be placed in every CO. Siting equipment at all COs for a CLEC would likely be prohibitive due to co-location, line leasing, and equipment costs. This is an important point. Previously, we noted that the maximum coverage of xDSL equipment was limited to a service distance of 18,000 ft. extending from a central office. However, this does not mean that all households within 18,000 ft. of a CO will have service access to xDSL, because the necessary equipment may not exist at all COs. In addition, because xDSL is a premium service, providers are also aware of potential demand for a given area. With installation charges approaching $300 and monthly service fees that range between $50 and $200, only a limited number of households can afford such service.

Undoubtedly, market conditions and competitive strategy play a major role in the provision of xDSL service. The capital requirements for CLEC entry into the xDSL market can be prohibitive. The combination of digital switches (approximately $7,000 for every 250 subscribers), co-location costs ($1,500 – $2,500 per month), and line leasing fees (variable) require a substantial initial investment with continuing fees.

Therefore, given a set of market conditions, the expected costs of market entry must be lower than the expected revenues. Considering that xDSL providers are profit maximizing firms,

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37 There are many different varieties of DSL switches on the market. Smaller switches are designed for small business/offices, higher capacity switches are designed for North American Incumbent Local Exchange Carrier (ILEC) and Competitive Local Exchange Carrier (CLEC) networks. The larger capacity switches are often placed in a CO. For example, the Cisco 6160 IP DSL Switch is a 256 port digital subscriber line access multiplexer (DSLAM) designed for large-scale deployment of higher-performance, multiservice, and profit centered Digital Subscriber Line services. List price as of May, 2000 was $6,900 (Cisco 2000).

38 Recent technological advances in the local loop actually extend the reach of xDSL service. Next generation digital loop carriers utilize a hybrid transmission system (copper and optical fiber) to aggregate xDSL traffic from multiple premises, multiplex it (FDM or DSLAM) and send it back to the CO for eventual transmission to the commercial Internet (Newton, 2000). It should be noted, however, this type of local infrastructure is the exception, not the norm.

39 Installation and service fees can vary quite dramatically. Some companies offer a complete rebate on hardware and installation fees. Others still charge fees to account for the overhead associated with co-location. Many believe the RBOCs engage in predatory pricing as a means to eliminate competition (Kushnick, 2001; NewNetworks, 2001). Therefore, CLECs are frequently unable to offer competitive prices and installation rebates similar to the RBOCs.
entry costs and expected profits certainly motivate their decisions concerning which markets to enter and where in those markets to locate equipment. In turn, thorough examination of the market forces that shape xDSL service provision is important in being able to assess and evaluate the efficiency and equity of broadband access. Further, considering the nature of xDSL service, a spatially based analysis of xDSL equipment location at COs will provide additional insight into the construction of the digital divide.

7.3 Spatial Modeling Approach

The previous discussion highlights the considerations many xDSL providers face when deciding where to locate or co-locate required hardware at COs in order to provide xDSL service. Moreover, the discussion also illustrates many of the obstacles residential and business customers face when trying to establish broadband access. This section outlines a methodological approach for evaluating xDSL service in a geographic information system based environment.

7.3.1 Study Area

The analysis will focus on Franklin County in Central Ohio, shown in Figure 7.3. Covering 540 square miles, 1997 estimates indicate that Franklin County has a population of over 1,000,000, while the county seat of Columbus has a population of 669,285. There are 39 central offices (CO) serving Franklin County and portions of adjacent counties. As mentioned previously, COs and the wire-centers they house act as the service hubs for xDSL access. Recall that the 12,000 ft. coverage radius represents the geographic extent to which many commercial xDSL providers are able to provide service. Note that even under the optimistic assumption of fully equipped COs, many of the residential and business customers in these wire-center service areas will find xDSL service unattainable. Figure 7.3 depicts the 12,000 ft. potential service areas that would result if all COs were equipped to provide xDSL service.
Figure 7.3: Wirecenters and Potential xDSL Coverage
In this “best case” scenario, 20% of the residents in Franklin County would not be covered within the 12,000 ft. service range if all COs were xDSL equipped. The demographic breakdown of these residents indicates that 24.7% of the Caucasian population in Franklin County would not be covered. Conversely, only 20.8% of the African American population would lack coverage. Where income is concerned, the median income of those locations potentially provided coverage ($40,036) is actually lower than the median income of those locations that are not covered ($46,418). Finally, 77% of the residents in Franklin County with a bachelors or graduate degrees are within the 12,000 ft. xDSL service radius.

Because xDSL service from a central office covers a fixed geographic area (12,000 ft.), deciding which COs to locate xDSL hardware is important both in terms of company profitability and equity. In essence, if the xDSL provider can supply service to a population, profits are generated. However, the decision to locate hardware is an expensive one. Aside from the initial cost of equipment, co-location by a CLEC in a central office owned by an incumbent local exchange carrier is also expensive. Paradyne (2000) estimates that 200 DSL customer lines are necessary on a co-located DSLAM to make co-location profitable. Again, this decision-making framework has serious implications for service equity. The objective of xDSL providers is to maximize their profits. Therefore, given a budget constraint, the most efficient strategy for establishing a strong return on investment is to target their xDSL equipment installation for COs serving geographic areas that contain a high number of potential customers that are interested in (and able to afford) xDSL service. This suggests that many areas might well be excluded from xDSL service because of their socioeconomic characteristics.

7.3.2 Evaluating xDSL Coverage

Geographic information systems (GIS) and associated spatial models offer substantial capabilities for evaluating potential xDSL service and the possible inequities of such service. The

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40 In the telecommunication industry this is known as “cream skimming”. RBOCs enjoy a significant competitive advantage in this respect. As Kushkin (2001) notes, because they have first access to phone customers, the RBOC can offer its own broadband products and services before a competitor.
ability to represent, manipulate, and analyze spatial information using a GIS makes it possible to evaluate xDSL market opportunities. For example, US Census information on socioeconomic and demographic characteristics is available for use in most commercial GIS packages. Further, standard GIS functionality enables one to examine spatial relationships. This might consist of a simple study where a 12,000 ft. buffer is applied to every CO, as shown in Figure 7.3. Subsequently, the demographic composition of these service radii may be evaluated, as was done in the previous section. Recognizing the significant costs associated with xDSL service establishment and the coverage limitations associated with xDSL service, more sophisticated analytical techniques would be valuable here. Such techniques should enable service placement scenarios to be evaluated, particularly within a commercial GIS environment, with the ultimate goal being assessment of potential xDSL service and its resulting inequities.

Given the need to select xDSL service locations and the notion of xDSL coverage, the maximal covering location problem (MCLP) introduced by Church and ReVelle (1974) is a useful spatial modeling approach in the context of high speed Internet access. The objective of the MCLP is to locate a prespecified number of xDSL service facilities in such a manner that the number of people not served within the maximal service distance of 12,000 ft. is minimized. This is identical to maximizing the number of people serviced within the 12,000 ft. service distance (Church and ReVelle, 1974).

The MCLP requires that potential facility sites be predefined and finite in number. Also, the demand areas needing coverage are fixed and finite. Finally, each demand location has a weight (population, number of households, etc.) related to the potential demand for xDSL service. If one assumes that facility costs are constant, the constraint on locating a fixed number of facilities is equivalent to a budget constraint (Church and ReVelle, 1974; Church, 1984). With respect to xDSL service deployment, the constant fixed cost structure is realistic. xDSL providers typically locate identical DSLAM equipment, such as the Cisco 6160, in each CO. Because the incumbent local exchange carrier (SBC-Ameritech) in Franklin County owns 100% of the COs
(excluding wireless), co-location and line-leasing fees are also fixed for CLECs. The integer
programming formulation of the MCLP for xDSL siting is as follows:

Minimize \( Z = \sum_i a_i y_i \) \hspace{1cm} (1)

subject to

\[
\sum_{j \in N_i} x_j + y_i \geq 1 \hspace{1cm} \forall i \hspace{1cm} (2)
\]

\[
\sum_j x_j = p \hspace{1cm} (3)
\]

\[
x_j \in (0, 1) \hspace{1cm} \forall j \hspace{1cm} (4)
\]

\[
y_i \in (0, 1) \hspace{1cm} \forall i
\]

where

\( i \) = the set of service demand locations

\( j \) = set of existing COs (potential facility sites)

\( d_{ij} \) = shortest distance from demand location \( i \) to potential facility \( j \)

\( S \) = service coverage distance (12,000 ft.)

\( N_i \) = \( \{ j \mid d_{ij} \leq S \} \)

\( a_i \) = service demand of area \( i \)

\( p \) = number of xDSL facilities to be located

\[
y_i = \begin{cases} 
1 & \text{if a service demand location is not provided coverage} \\
0 & \text{otherwise}
\end{cases}
\]

\[
x_j = \begin{cases} 
1 & \text{if xDSL hardware is located at site } j \\
0 & \text{otherwise}
\end{cases}
\]

The MCLP objective (1) is to minimize the total potential demand for xDSL service that is not provided suitable coverage. Constraint (2) accounts for suitable coverage of demand sites.
Constraint (3) requires \( p \) xDSL facilities to be located. Constraint (4) imposes integer requirements on decision variables.

The MCLP provides an appropriate and meaningful spatially-based modeling approach for examining xDSL service provision and equipment location. First, given the spatial limitations of xDSL technology, the coverage area limitation of 12,000 ft. is an integral component of the MCLP. Second, the MCLP helps operationalize the goals of profit maximizing xDSL providers by minimizing the amount of potential demand that is not provided suitable coverage based on the aforementioned spatial limitations of xDSL service. Finally, given the capital requirements for providing xDSL service, the MCLP can reflect budget constraints by modeling the variations in potential demand covered as the number of facilities \( (p) \) is varied.

7.3.3 Considerations

In order to carry out the analysis of xDSL service provision, there are a number of issues regarding spatial representation and coverage that need to be addressed. Methodological concerns are scale, the representation of facilities, the capacity of facilities, and the representation of regions in coverage analysis. For the purposes of this chapter, service coverage emanates from a point-based location, corresponding to the central office (CO). US Census block groups represent demand for xDSL service and the block group centroids are used to reflect demand locations for xDSL service in Franklin County. This information is available for use in most commercial GIS packages, as noted previously. Coverage is provided if a block group centroid is within 12,000 ft. of a CO. More detailed discussions of scale, unit definition, and spatial representation, can be found in Openshaw and Taylor (1981) and Murray and O’Kelly (2000). A final point is that the model utilized in this chapter is uncapacitated, thereby implying that COs have the capability to serve all realized demand.
7.3.4 Measuring Demand

Given the modeling framework discussed previously, it is important to derive an appropriate measure of potential demand, $a_i$. Many possibilities exist because $a_i$ can be interpreted in different ways. Two variants of demand are considered in this study. Each variant encapsulates basic notions of potential service demand, and at the same time, represents realistic market conditions for xDSL providers wishing to maximize profits on a limited budget in the study area.

One aspect of potential demand explored in this chapter places emphasis on xDSL service to businesses. Although many larger corporations can afford leased line access, such as OC-48, most small to medium sized businesses are looking for a low-cost alternative for broadband access such as xDSL\footnote{The cost of leased line access for businesses can be substantial. For example, Qwest Communications provides fractional T-3 connections (3 Mbps) for a monthly fee of approximately $5,000.}. Thus, this chapter utilizes daytime population (1997 estimates) as a surrogate for potential demand, $a_i$. There are significant shifts in the population patterns of most metropolitan areas between the hours of 9:00am to 5:00pm. This shift occurs between residential areas and areas of business/employment. Therefore, the utilization of daytime population represents a good estimate of demand for xDSL from the business community because it accounts for these population shifts\footnote{Daytime population estimates are available from commercial data vendors such as Claritas or Compusearch.}.

The second aspect of demand explored in this chapter places emphasis on residential broadband service. Given the potential expense of residential xDSL service to the consumer (activation fees, monthly service), income level is an important determinant of demand for broadband access. Further, many studies indicate that level of education is intimately linked to demand for Internet access (Hoffman and Novak, 2000; NTIA, 1999). This suggests that three variables (number of households, income, and education) need to be considered simultaneously.
when evaluating demand for residential broadband Internet service. This second interpretation of potential demand will be denoted as $\hat{a}_i$.

With these two interpretations of potential demand, it is possible to simultaneously integrate both aspects using a bi-objective extension to (1) as follows:

$$
\text{Minimize } Z = \sum_i (\beta a_i + \lambda \hat{a}_i) y_i
$$

where

$$
\beta = \text{ weight associated with business demand}
$$

$$
\lambda = \text{ weight associated with residential demand}
$$

The model highlighted in (5) subject to constraints (2) – (4) will be referred to as the BMCLP (Bi-objective Maximal Covering Location Problem). The holistic approach to xDSL service provision facilitated by the BMCLP allows for the identification of robust CO locations providing good coverage to both business and residential users. By utilizing the BMCLP for analysis, alternative demand characteristics may be specified using different weights (reflecting relative importance of the two types of demand). This may be helpful in uncovering possible spatial disparities in xDSL service for a region. This is achieved by identifying non-inferior solutions to the BMCLP. The weighting method outlined in Cohon (1978) is utilized for obtaining non-inferior tradeoff solutions in this chapter, where weights on the two objectives are varied between 0 and 1, with $\beta + \lambda = 1$.

Given that the weighting method is known to miss non-inferior solutions when applied to integer programs (see Cohon 1978), it is necessary to explore the non-inferior solution duality gaps. The constraint method is used on conjunction with the weighting method in order to obtain all non-inferior solutions.

7.3.5 Demand Index

Given that total population is not always the most appropriate indicator of demand for xDSL service, one approach for deriving an effective measure of demand is through an index.
We utilize a mathematical approach for the derivation of a demand index as specified by Murray and Davis (2001):

\[ i = \text{index of geographic areas}, \]

\[ k = \text{index of indicators/variables}, \]

\[ w_k = \text{importance weight of indicator } k, \]

\[ R_{ik} = \text{derived value of indicator } k \text{ in area } i, \]

Potential residential demand may be specified as follows:

\[ \hat{a}_i = \sum_k w_k R_{ik} \quad (6) \]

\( R_{ik} \) values are derived from raw data such as household counts, median income levels, or level of education. It is important to ensure that these variables are standardized in a sensible way. Such standardization facilitates interpretation and allows for impartial comparison across all indicator variables. In this chapter indicator values are limited to a range of 1 – 10. A value of 10 indicates the most demand for service and a value of 1 indicates the least demand for service. As a result, the values ranging between 1 and 10 represent varying levels of potential demand for xDSL access. Thus, \( R_{ik} \) has associated with it the following interpretation:

\[ R_{ik} = \begin{cases} 1 & \text{least demand for service} \\ 10 & \text{most demand for service} \end{cases} \]

A more detailed discussion of demand index generation and interval standardization can be found in Murray and Davis (2001).

As mentioned previously, the demand index employed in this chapter utilizes household counts, median income, and education (bachelors + graduate degrees) as proxies for xDSL demand. All variables are weighted equally, with \( w_k = 1 \). The most desirable areas for xDSL service are those that rate highly across all standardized indicator variables. This approach is useful when multiple variables are necessary, particularly ones that are not readily combined or
integrated. For example, at the block group level, median income and education can be represented in different ways. Median income is a single measure that represents the "median" income of all households in a particular block group. Education is frequently represented as a series of counts indicating the varying levels of educational attainment (high school, bachelors degree, etc.) for residents in a block group. Although these two variables are difficult to compare impartially in their raw form, they are easily combined and evaluated using a demand index.

7.4. Application Results

The analysis was carried out on a Pentium III/1000 personal computer. ArcView version 3.2 was utilized to manage, manipulate, and analyze associated CO coverage of the US Census block group representation of Franklin County, Ohio. There are 39 COs and 942 block groups for this region. The planning application using the BMCLP was integrated into ArcView utilizing an Avenue script to evaluate coverage and write the associated integer program to a text file. The problem is then solved externally to ArcView using CPLEX version 6.53. A result file is then exported from CPLEX and read into ArcView for subsequent display and analysis.

7.4.1 xDSL Service Provision

Figures 7.4a and 7.4b depict the cost-effectiveness curves generated by solving the BMLCP for a range of $p$ values applied to the 942 block groups of Franklin County and 39 central offices using a maximal service distance of $S = 12,000$ ft. Figure 7.4a displays the results of placing a weight of 1 on business demand ($\beta = 1$) and a weight of 0.0 on residential demand ($\lambda = 0$). This optimizes coverage with respect to business demand only given the utilized set of weights. Alternatively, Figure 7.4b displays the results of placing a weight of 1 on residential demand ($\lambda = 1$) and a weight of 0.0 on business demand ($\beta = 0$). This now optimizes residential coverage only. In both cases neither total residential nor total business demand can be satisfied due to the service distance limitation of xDSL coverage.
Figure 7.4: A: Cost-Effectiveness Curve for Maximizing Daytime Population in DSLAM Equipment Location
B: Cost-Effectiveness Curve for Maximizing Derived Demand Covered in DSLAM Equipment Location
One of the advantages of utilizing the BMCLP in a decision-making framework is the ability to generate demand coverage cost-effectiveness curves associated with varying the number of equipped COs. In the case of xDSL coverage, as investment increases (more central offices upgraded for service) the effectiveness of such upgrades is reflected in the amount of potential demand covered. As Figures 7.4a and 7.4b illustrate, the rate of increase in demand covered by the additional equipped COs decreases as \( p \) increases. Given the information displayed in these figures, profit-maximizing firms would need revenue estimates to determine the last marginal facility to locate in order to turn a profit. Therefore, the selection of the most cost effective configuration of xDSL hardware upgrades clearly sits with the firm seeking to provide service in Franklin County. Although data pertaining to expected revenues for the residential broadband market in Franklin County are unavailable, it is worth exploring the potential spatial outcomes of xDSL service provision in order to better understand how disparities in xDSL broadband coverage are likely to be manifested in this competitive market.

Although the potential for exploring spatial disparities in broadband access exists at each of the points on the cost-effectiveness curves in Figures 7.4a and 7.4b, we have selected a single point for more extensive analysis. By examining the spatial configuration of COs selected for equipment upgrades, it will be possible to gain some insight into the potential nature of the digital divide likely to emerge in this region.

7.4.2 Spatial Coverage Associated with Equipping Twelve Central Offices (\( p = 12 \))

Shown in Figures 7.4a and 7.4b is that for \( p = 12 \) approximately 70% of both business and residential demand is covered by xDSL service in Franklin County. Considering that the cost of hardware (DSLAM) for each CO is $6,900 (giving a total hardware costs of $82,800), \( p = 12 \) represents a good, mid-range solution illustrating the potential cost tradeoffs involved in siting DSLAMs. Of course, cost estimates assume that a single DSLAM has enough capacity to support all demand assigned, as the BMCLP is uncapacitated, and does not include co-location fees or line-leasing fees administered by the incumbent local exchange carrier. The BMCLP also
allows one to identify non-dominated solutions for this level of investment with respect to both business demand, \( a_j \), as well as residential demand, \( \hat{a}_j \).

Figure 7.5 shows the non-inferior tradeoff curve for \( p = 12 \) generated using the weighting and constraint methods detailed in Cohon (1978).\(^{43}\) With 12 COs xDSL enabled and an emphasis on business broadband provision, Solution 1 in Figure 7.5 represents a configuration that is able to provide service to 67.31% of the residential demand and 71.70% of the business demand in Franklin County. This solution was obtained by maximizing business demand without any constraint on residential demand. As illustrated in Figure 7.6, the spatial arrangement of CO coverage for Solution 1 serves much of Columbus and its suburbs, including the communities of Dublin, Westerville, Worthington, and Reynoldsburg. The socioeconomic and demographic composition of the covered areas is documented in Table 7.1. For example, Solution 1 covers 69.14% of the residents in Franklin County with a bachelors or graduate degree. In addition to summarizing the proportion of demand covered for each non-dominated solution found in Figure 7.5, Table 7.1 also includes the socioeconomic and demographic characteristics for siting at all 39 COs as well as 21 COs. The significance of these two alternatives is that they both provide the maximum coverage achievable in this region. One is able to equip only 21 COs rather than 39 in order to serve this region. Also shown in Table 7.1 are the summary characteristics for the entire Franklin County region discussed previously.

The increasingly complex nature of the digital divide becomes evident when one compares the spatial configurations of the BMCLP shown in Figures 7.6, 7.7, and 7.8, with summaries detailed in Table 7.1. For example, when xDSL service coverage is optimized with respect to business demand (Solution 1), the African American population attains slightly better xDSL coverage than the Caucasian population. In part, the differences between demographic

\[^{43}\] The weighting method was used to find solutions 1, 2 and 4, with weights varied in increments of 0.01. Solution 3 was found using the constraint method to explore the duality gaps (in increments of 1.0).
Figure 7.5: Non-inferior Tradeoff Curve for $p = 12$
Figure 7.6: Non-Dominated Tradeoff Solution # 1 for p = 12
<table>
<thead>
<tr>
<th>Solution</th>
<th>$p$</th>
<th>% Residential Demand</th>
<th>% Business Demand</th>
<th>% Households</th>
<th>Median Income</th>
<th>% Caucasian</th>
<th>% African American</th>
<th>% Higher Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>67.31</td>
<td>71.70</td>
<td>64.46</td>
<td>39,821</td>
<td>61.00</td>
<td>65.15</td>
<td>69.14</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>68.44</td>
<td>69.99</td>
<td>61.49</td>
<td>38,786</td>
<td>57.59</td>
<td>66.92</td>
<td>62.03</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>68.71</td>
<td>57.20</td>
<td>66.07</td>
<td>46,698</td>
<td>62.45</td>
<td>68.16</td>
<td>69.68</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>68.78</td>
<td>55.39</td>
<td>64.48</td>
<td>38,71</td>
<td>60.23</td>
<td>74.37</td>
<td>64.57</td>
</tr>
<tr>
<td>All COs Equipped</td>
<td>39</td>
<td>81.37</td>
<td>84.32</td>
<td>77.62</td>
<td>40,036</td>
<td>75.29</td>
<td>79.17</td>
<td>77.12</td>
</tr>
<tr>
<td>21 COs Equipped**</td>
<td>21</td>
<td>81.37</td>
<td>84.32</td>
<td>77.62</td>
<td>40,036</td>
<td>75.29</td>
<td>79.17</td>
<td>77.12</td>
</tr>
</tbody>
</table>

Franklin County

<table>
<thead>
<tr>
<th>Total Households</th>
<th>Median Income</th>
<th>Caucasian</th>
<th>African American</th>
<th>Higher Education*</th>
</tr>
</thead>
<tbody>
<tr>
<td>404,989</td>
<td>41,044</td>
<td>821,232</td>
<td>167,525</td>
<td>197,915</td>
</tr>
</tbody>
</table>

*Bachelors + Graduate degrees
**21 xDSL enabled COs cover 100% of potential demand

Table 7.1: Residential Coverage Statistics
coverage can be attributed to a large population of minority black residents living near the Columbus city center, an area receiving excellent coverage.

Evident in Table 7.1 is the dramatic shift in socioeconomic and demographic characteristics associated with the various tradeoff solutions indicated in Figure 7.5. For example, when xDSL service coverage is optimized with respect to residential demand (Solution 4), 68.78% of the potential residential demand and 55.39% of the potential business demand is covered (see Table 7.1). However, African Americans attain significantly better potential access to xDSL than Caucasians in this case. In fact, when the demographic composition of Solution 4 is compared to Solution 1, the percentage of African Americans covered increases almost 10%. Much of this difference can be explained through a careful examination of the spatial configuration of Solution 1 shown in Figure 7.7. Although not selected in Solution 1, the Gahanna central office is provided coverage in Solution 4. In addition to covering Gahanna, the 12,000 ft. service radius of this CO also covers the Linden district of northeast Columbus. Similar to areas near the Columbus central business district, the Linden district contains a large minority population. Because the model includes household density as an important parameter, it does not always “cherry-pick” the high-income neighborhoods that one might expect. Where the model is concerned, each coverage area is a pool of potential customers and revenue. Therefore, a high-density - low-income pool and a low-density - high-income pool can be similarly attractive. Although xDSL providers often target high-income neighborhoods for service provision, if one follows the logic previously outlined, it is clear that dense, high-income neighborhoods with a well-educated populace are more desirable. True to form, neighborhoods such as the German Village area of South Columbus are given priority over less-dense suburban locations such as Dublin in this case.

If unhappy with Solution 4, more emphasis can be placed on business demand. For example, Solution 3 covers 68.71% of the potential residential demand and 57.20% of the

\footnote{Although Dublin’s residential demand is low density and difficult to cover from its existing CO, the city remains a prime candidate for a remote DSLAM or next generation digital loop carrier.}
Figure 7.7: Non-Dominated Tradeoff Solution # 4 for p = 12

Franklin County Central Office
12,000 ft. Service Coverage

New Albany
New Rome
Grove City
Obetz
Groveport
Reynoldsburg
Gahanna
Westerville
Columbus
Hilliard
Upper Arlington
Dublin
Worthington
Canal Winchester
Worthington
Westerville
New Albany
potential business demand (see Table 7.1). The percentage of African Americans covered decreases by 6% (Gahanna and Linden are no longer covered), but the median income of areas receiving coverage increases by $8,000. As Figure 7.8 illustrates, the city of Dublin is provided coverage in this case. The dramatic shifts in spatial arrangement and socioeconomic and demographic composition of Solutions 1, 3, and 4 are explained by examining the local geography of Franklin County45.

With thousands of well-educated residents, Dublin is an affluent suburb located in northwest of Columbus. One would expect that the potential demand for xDSL service in this area to be high and service coverage desirable. However, as illustrated in Figure 7.7, Dublin is not included when residential demand is emphasized (Solution 4). Conversely, as Figures 7.5 and 7.8 illustrate, the Dublin CO is selected when, to satisfy an additional 1.81% of the business demand, 0.07% of the residential demand is sacrificed (Solution 3). Dublin is a desirable area for xDSL when business demand is more influential (Figure 7.6).

There are several reasons why the coverage of Dublin fluctuates when considering the spatial characteristics of the digital divide. First, a significant portion of Dublin’s residential population lies outside the 12,000 ft. coverage area. In fact, it should be noted that Dublin’s CO lies at the southeast corner of the city limits. The failure to cover Dublin in Solution 1 reflects the geographic ramifications of CO location and the distance constraints of xDSL coverage. Current trends indicate that Dublin continues to grow away (north and west) from its CO. Therefore, even if xDSL companies were able to cover beyond 12,000 ft. on a regular basis, much of Dublin would remain incapable of receiving xDSL service. In addition, because such a significant portion of Dublin’s residential growth is stretching into an adjacent county (Delaware), wire-center service area boundaries are also forced to extend into Delaware County to insure that standard telephone service and exchanges stay consistent with those portions of Dublin located in Franklin County. These high growth areas are often targets for digital loop carriers, load coils and bridge

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45 Nine of the twelve sites coincide across the non-dominated solutions (Columbus 8, Columbus 9, Columbus 10, Columbus 11, Columbus 12, Upper Arlington 1, Upper Arlington 2, Westerville 2, Worthington 1). This suggests a certain degree of robustness in these sites.
Figure 7.8: Non-Dominated Tradeoff Solution # 3 for p = 12
taps. This means that the vast majority of Dublin (especially its newest developments) is inherently difficult to cover. Second, with 2,500 businesses in the city of Dublin that employ more than 60,000 workers (roughly double its population) and a highly developed business corridor (I-270), Dublin is a destination for the Franklin County workforce. This is one of the reasons that Dublin acquires coverage when additional emphasis is placed on business demand in the BMCLP (Solution 3). These results clearly indicate that CO locations and local geography play an important role in xDSL broadband access for cities such as Dublin.

7.5 Discussion and Conclusions

Existing literature on the digital divide suggests that socioeconomic status (affordability of computer hardware, Internet access, exposure) and demographic characteristics play a major role in determining the frequency and quality of Internet access and use (Hoffman and Novak, 2000; NTIA, 1999). The results of this study suggest the presence of a more complex and multifaceted digital divide than previously documented. Although this newly forming divide includes demographic characteristics and socioeconomic status, the spatial manifestations of the digital divide for broadband access are somewhat counterintuitive. Instead of challenged inner-city populations lacking adequate infrastructure, many of the more affluent suburban locations in Franklin County are likely to be without xDSL coverage.

The spatial disparities in broadband xDSL Internet access are conceived in two different manners. The physical architecture of the copper infrastructure severely limits the type and quality of Internet access that is available via xDSL technology. The most significant aspect of these physical limitations is the proximity of a household or business to a central office/exchange. Although the current geographic limits of xDSL transmission technology are approximately 18,000 ft., xDSL service providers rarely guarantee high quality service at that distance. A more realistic geographic estimate of high-quality, low interruption service is 12,000 ft. Additional physical limitations include the quality of copper wiring, wire gauge, and presence of digital loop carriers, bridge taps, and load coils. Given this, a large segment of the potential Internet community will
be underserved in terms of quality and access by xDSL technology in its current state. More importantly, from a purely geographic standpoint, this emerging divide does not necessarily discriminate against stressed inner-city locations and people (minorities) in terms of Internet access. Results suggest that the rapidly growing, affluent suburbs of Franklin County (Hilliard, Dublin, New Albany, and Canal Winchester) are the most likely to suffer from the infrastructure challenges presented by xDSL service. In most cases, this lack of coverage can be attributed to the spatial characteristics of suburban growth and CO location. Although results suggests that many of the COs located in distressed sections of Columbus (proximal to the CBD) are likely candidates for xDSL upgrades, the residents of these neighborhoods often lack the financial resources to leverage any benefit. However, CO upgrades in distressed neighborhoods do represent a positive addition to the long-term economic viability of an area.

The geographic provision of xDSL service is likely to be a function of profit seeking firms. The combination of DSLAM costs ($6,900), co-location fees ($1,500 per month, per rack), and line leasing fees (variable) make xDSL setup costly for competitive local exchange carriers. Therefore, although many central office locations are available for DSLAM installation, one might suggest that only those COs with a potential for immediate return on investment will be selected for hardware upgrades. The results presented in this chapter point to a significant public policy issue many metropolitan areas will face over the next several years. In essence, how can equitable broadband access be achieved/provided for all groups, regardless of race, income, or location? The answers to this question are elusive. Cities such as Palo Alto, California have constructed their own fiber optic backbone to provide access alternatives to their community (Oram, 1999). Unfortunately, broadband access costs for single-family households are still prohibitive. In any case, there is little doubt that this issue will continue to be a focus for both the government and private sectors for years to come.

This chapter provides a look at the impacts that local infrastructure have on Internet access. While it focuses on only a small part of the residential broadband market (xDSL), it does provide a fairly comprehensive examination of the limitations that local geography can impose on
broadband Internet access. Further, this chapter partially addresses the ongoing challenges for equitable service provision in an increasingly privatized market for Internet access.
As economic globalization continues to evolve, society becomes increasingly intertwined in a web of information. The Internet, a network of networks, both enables and defines the flow of information between continents, countries, cities, corporations, and individuals. Although the Internet is growing in popularity, it is far from a global medium. Massive segments of the global population remain unable to access the Internet. Questions concerning Internet accessibility are important, even in the United States, which is largely viewed as the most "wired" country in the world. Although the demographic and socioeconomic characteristics of this digital divide are well documented, the spatial aspects of the digital divide have received relatively little attention. The goals of this thesis were twofold. First, by exposing the salient characteristics of geography and space as they relate to the Internet, this thesis attempted to explore the digital divide by examining issues of accessibility across three spatial levels. Second, this thesis attempted to outline the evolving economic geography of the Internet (across the same three spatial levels) and evaluate its impact on both urban and rural areas. The following subsections more thoroughly detail the unique contribution of this thesis in a chapter-by-chapter summary.

8.1 Summary of Thesis

National Level

Chapters 3 and 4 examine city accessibility to the Internet at the national level. Chapter 3 stresses the role of interconnection to the commercial Internet. It was shown that interconnection options, as defined by points of presence (POP), displayed an uneven spatial
distribution. Larger markets for information services, such as Chicago, New York, and San Francisco displayed significant agglomerations of interconnection infrastructure. In addition, relatively smaller markets, such as Portland, Austin, and Charlotte, also displayed clusters of POP infrastructure. Chapter 3 suggests that local economic factors, such as the presence of firms ‘rooted’ in the emerging digital economy attract infrastructure investment, because these firms demand interconnection options. Innovative activity, as defined by the number of utility patents granted in 1999, was also correlated to relatively high concentrations of Internet access infrastructure. Finally, Chapter 3 suggests that Internet infrastructure growth displays several unique spatial characteristics. First, growth is no longer restricted to those cities with historic concentrations of telecommunication infrastructure (e.g. network access point or metropolitan area exchange cities). Relatively smaller cities in spatial proximity to major markets, such as Milwaukee (proximal to Chicago) and Tucson (proximal to Phoenix), are benefiting from increased infrastructure investment. Second, locations serving as intermediary points between two larger markets (e.g. Portland and New Haven) also display significant growth in access options.

Chapter 4 takes a different tack on accessibility, examining the relative location of cities on the commercial Internet. Utilizing an array of aggregate network and graph theoretic measures, Chapter 4 not only defined a standardized framework for evaluating network accessibility, but results suggested that those cities housing a major network access point (NAP) or metropolitan area exchange (MAE) are significantly more accessible than those cities without such infrastructure. This means that the traditional strongholds of Internet accessibility, Washington, San Francisco, New York, Chicago, Dallas, and Los Angeles remain the most accessible. The only exception to the NAP/MAE situation is Atlanta, which serves as a major Internet gateway to the Southeast. Results also indicate that more regional gateways emerged in the United States between 1997 and 2000. Denver, Salt Lake City, St. Louis, and Kansas City all display strong accessibility to the commercial Internet, serving as regional switching points and hubs for Internet traffic. In addition, geographically remote cities like Miami and San Diego are no
longer relatively isolated from the commercial Internet, as both display fairly strong network accessibility measures.

A final point worth mentioning at the national level concerns questions of scale and analysis. Both Chapters 3 and 4 incorporate accessibility measures at the citywide and MSA-wide levels. There are significant differences when both sets of results are compared. For example, although Chicago is the most well connected city (Chapter 4), San Francisco-Oakland-San Jose is the most well connected MSA. Aside from the analytical implications of defining the appropriate spatial units for analysis in telecommunication research, one must also consider the evolving economic geography of the Internet. As outlined in Chapters 1 and 2, although cities remain important foci for economic activity, agglomerations of infrastructure and the economic space they help define are not neatly tied to city boundaries. Therefore, analyses that incorporate more broadly defined economic regions (e.g. Silicon Valley or the San Francisco-Oakland-San Jose MSA), often provide more contextual insight to the processes shaping infrastructure investment and Internet connectivity.

**Regional Level**

Chapter 5 extends the scale of analysis to the regional level by utilizing domain names as surrogates for Internet activity. Also included in this chapter was a standardized framework that helped detect clusters of Internet activity at smaller geographic scales. Similar to the national scale analysis, results suggest that Internet activity is hierarchical in nature, with larger urban centers displaying more activity than smaller rural locations. Regional economic structure also plays a role. As one might expect, regions with larger concentrations of firms rooted in information technology display a higher rate of Internet activity than those regions without such firms. Results also suggest that a certain amount of activity spillover is taking place between central cities and their adjacent suburban or exurban neighbors. This unexpected result is partially fueled by the continued growth of ‘edge city’ style developments outside of city centers. With ample office space, access to transportation infrastructure, and largely white collar
workforces, edge cities such as Dublin, Ohio are attracting a significant amount of Internet related activity.

Chapter 6 extends the regional analysis with an emphasis on broadband accessibility. Results for Ohio suggest that the urban-rural divide is accelerating. Much of this can be attributed to the deregulation of the telecommunication industry in 1996. Because telecommunication companies are no longer required to provide equal levels of service to all locations, many of the newly surfing competitive local exchange carriers (CLEC) are implementing services in those markets deemed most profitable. As expected, urban markets, with high household densities offer the best turnaround on infrastructure investment for the CLECs. This means that many rural locations, especially Appalachian Ohio, are left underserved by newer Internet access technologies such as xDSL. Although this may be the case, Chapter 6 also documents several local initiatives to bring broadband access to more rural locations in Ohio. Only time will tell if these initiatives will be successful.

Local Level

Chapter 7 extends the analysis of broadband xDSL access to the sub-metropolitan level in Columbus, Ohio (Franklin County). Utilizing a bi-objective maximal covering model in a GIS environment, the spatial limitations of xDSL technology and their impact on local Internet accessibility are explored. Results suggest that many of the more affluent locations in Franklin County have the potential inability to access xDSL services. As the development of new subdivisions continues in these suburban and exurban areas, the infrastructure supporting xDSL services remains static. Therefore, as the distance from existing central offices to these new developments increases, the ability to receive xDSL connections decreases. This suggests that many of the more established urban neighborhoods, near the city center, offer better potential for broadband accessibility than their suburban counterparts. Moreover, this suggests that many of the more disenfranchised and economically challenged districts near city centers offer better potential for Internet access.
8.2 Discussion

In terms of a final reflection on the accomplishments of this thesis, two major points are worth addressing. First, it was demonstrated that the digital divide and the economic development opportunities fueled by the Internet have a clear and remarkably important spatial component. At the national level, evidence suggests that accessibility to fiber optic backbones, and the geographic parameters associated with backbone performance (topology, relative network location) are important factors in both corporate growth and economic development. At the regional level, spatial disparities in the presence of advanced telecommunication systems and access can be indicative of both an extremely competitive telecommunications market, centered on profit taking rather than equitable service, and a regional economic structure unfit for information intensive industries (undereducated workforce, poor regional capacity, etc.). At the local level, a simultaneous evaluation of both the technical and sociodemographic nature of the digital divide was explored, highlighting the potential for a very counterintuitive spatial and socioeconomic divide where residential broadband access is concerned.

8.3 Future Research Directions

While the work presented in this thesis increases our knowledge of the Internet, its economic geography, and the digital divide, several questions remain unanswered. First, the majority of this thesis concentrates on the ‘wired’ infrastructure of the commercial Internet and its impact on space. Results suggest that the evolving nature of Internet infrastructure reinforces old patterns of agglomeration. In part, cities remain important nodes because their centers are locations where the new fiber optic infrastructure converges. However, as wireless access and its supporting infrastructure continues to expand in the U.S., there is a possibility that many of the more rural locations will ultimately benefit from broadband Internet access. In effect, given the appropriate technological developments, wireless broadband may become as ubiquitous as the copper infrastructure supporting the analog telephone service of today. Clearly, more geographic research relating to the spatial characteristics of wireless broadband access is needed.
Future work will also encompass additional analysis with existing data. Broadband access continues to grow in Ohio at a significant pace, with more rural areas gaining access, or scheduled to gain access within the next two years. In addition to more empirical analysis of the infrastructure being necessary, it will be important to address the impact of public policy on infrastructure investment and demand. On a related note, as fiber optic networks continue to expand, there is the potential that the United States, Europe, and Asia will have “overbuilt” telecommunications capacity. For example, FLAG Telecommunications recently reported that its three-year old Europe to Asia 2x5 Gbps cable is just 25% filled. This overcapacity is echoed by a number of other companies, including Global Crossing, with only 3% of its 2.5 Gbps Japan to United States IP backbone. Again, it will be important to explore the ramifications of overcapacity in the system and its impact on the digital divide.
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