STATE AND LOCAL TELECOMMUNICATIONS NETWORKS: INSTITUTIONAL AND POLITICAL FACTORS INFLUENCING GOVERNMENT DEPLOYMENT STRATEGIES

by

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B.S., Physics
Syracuse University, 1993

Submitted to the Department of Electrical Engineering and Computer Science
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE IN TECHNOLOGY AND POLICY

at the

Massachusetts Institute of Technology

June 1996

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ABSTRACT

State and local governments are deploying telecommunications networks to facilitate applications in education, social services, and transportation. In some instances, these networks are being deployed by individual government agencies to support specialized applications without consideration of broader state and local government networking requirements. This thesis examines why separate government networks are being deployed and whether deployment strategies that take into consideration multi-agency networking requirements should be adopted.

A case study analysis of eight broadband telecommunications network deployments provides the substantive basis for the analysis presented in this thesis. Two of the cases focus on state-wide deployments intended to serve applications in education and social services. The remaining six cases focus on deployments intended to serve applications in transportation. The cases suggest that the causal factors for the deployment of separate networks are both institutional and political.

At an institutional level, the cases suggest that government agency staff typically have few incentives to promote the deployment of ubiquitous telecommunications networks, in part due to the delegation of authority, regulatory concerns, and agency culture.

At a political level, serious objections to the deployment of ubiquitous state and local telecommunications networks have been raised by the private sector. Private interests, including the Regional Bell Operating Companies, have lobbied heavily to limit the scope of public sector deployment of telecommunications networks and promote the use of leased services. Elected officials at the local, state, and national level have expressed sympathy for arguments against government owned networks.

Improved institutional arrangements that promote multi-agency deployment and utilization of government telecommunications networks are needed. Network interoperability and cost-effectiveness should not be compromised due to institutional obstacles or political conflict. The potential impact of information technology planning entities and the role of the United States Department of Transportation are briefly considered to illustrate how multi-agency initiatives could be promoted.

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ACKNOWLEDGMENTS

The author gratefully acknowledges the guidance and assistance of many individuals. Without their help, this thesis would not have been possible.

Gary Ritter of the Volpe National Transportation Systems Center provided substantial guidance during the development of the case studies. He offered advice on techniques for interviewing government agency staff and reviewed each of the initial case descriptions which were originally presented at the "Intelligent Transportation Systems Telecommunications Infrastructure Forum" hosted by the Volpe National Transportation Systems Center on April 27, 1995. Gary also reviewed a draft of this thesis before it was finalized May 10, 1996.

The interviewees for the case studies kindly took the time to candidly describe each deployment, providing insights into the planning and management process. Interviews were conducted with the following individuals: Bob McWithey, Director of Engineering, Iowa Communications Network; Laverne Holtorf, Communications Manager, Iowa Department of Transportation; Jane Patterson, Advisor to the Governor of North Carolina; Roberto Canales, Congestion Management Engineer, North Carolina Department of Transportation; Dale Ricks, Field Liason Engineer, Missouri Highway and Transportation Department; Bill Stoeckert, Manager of Highway Operations, Connecticut Department of Transportation; Vincent Avino, Principle Engineer, Connecticut Department of Transportation; Hal Decker, Transportation Engineer Three, Connecticut Department of Transportation; Ray Pardo, CA/T Manager of Highway and Central System, Bechtel/Parsons Brinckerhoff; David Nolle, CA/T Senior Communications Engineer, Bechtel/Parsons Brinckerhoff; Sergiu Luchian, CA/T Projectwide Engineer, Massachusetts Highway Department; Pat McGowan, (former) Assistant Traffic Management Engineer, Texas Department of Transportation - San Antonio District; Brian Fariello, Assistant Traffic Management Engineer, Texas Department of Transportation - San Antonio District; Charlie Felix, Senior Traffic Engineer, San Jose Department of Streets and Traffic; and Joe Baybado, Chief Right-of-Way Officer, Bay Area Rapid Transit.

Part of the research presented here was supported by the Volpe National Transportation Systems Center (DTRS-57-92-C-00054). Professor Dan Roos, Director of the Center for Technology, Policy, and Industrial Development, and the author presented a paper based upon the case studies at a unique day long workshop on "Intelligent Transportation Systems and the National Information Infrastructure" at Harvard University on July 13, 1995. A revised version of the paper will be published as a chapter in a forthcoming book from MIT Press (see references).

Appendix A was drafted during the spring of 1995 as a final paper for the course 1.212 "Intelligent Transportation Systems" which was taught by Professor Joe Sussman of the Department of Civil and Environmental Engineering. In his course, Joe provided a very useful introduction to the subject of Intelligent Transportation Systems.

The author also acknowledges the support of the Technology and Policy Program which provided funds for a teaching assistantship position while this thesis was being written during the spring of 1996. In this position, the author assisted with the instruction of the course TPP91 "Telecommunications Modeling and Policy Analysis" which focused on state and local deployment of telecommunications infrastructure.

Beyond the factual overviews provided in each case, the author is solely responsible for the ideas and opinions expressed in this thesis.

to James Russell Melcher

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1.0 INTRODUCTION: STATE AND LOCAL NETWORKS

State and local governments are major investors in information technology, spending as much as $30 billion per year according to some estimates.[1] Broadband telecommunications networks are being deployed by state and local governments to support novel applications in education, social services, and transportation.[2] Individual deployment costs range from hundreds of thousands- to hundreds of millions of dollars depending upon network scope and functionality.

A wide range of financial and institutional arrangements are being used to support state and local telecommunications infrastructure deployment. Financing mechanisms include direct expenditures from general revenues, bond instruments, and private sector direct investment. Private sector direct investment often involves institutional arrangements described as public-private partnerships or shared resources arrangements. Other institutional arrangements involve a purely public- or private sector role in network deployment.

Many network deployments are well publicized, receiving national and international attention, while others are relatively obscure. State-wide networking initiatives that support distance learning applications have perhaps received the greatest attention.[3] However, state and local governments also invest in information technology because of important but relatively unglamorous functions such as interconnecting dispersed welfare offices to a main-frame computer or providing telephony services within an individual government building through a Private Branch Exchange (PBX). Telecommunications infrastructure is also being deployed for emerging applications in transportation; Intelligent Transportation Systems (ITS) utilize information technology to improve mobility and generally provide higher quality transportation services to the public.

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[1] Richter, p. 65. "States are one of the largest consumers of telecommunications services. As new automated applications for public service delivery come online, state reliance on telecommunications will increase." National Governors' Association, p. 3.

[2] Broadband in this context refers to network capacities of at least 45 Mbps.

[3] For example, the Iowa Communications Network and North Carolina Information Highway are well publicized projects. These cases are discussed in chapter two.

Each of three main functions of state and local governments -- provision of educational services, social services, and transportation infrastructure -- are discussed below in the context of overall governmental goals and applications of information technology to achieve those goals.[4]

1.1 Education

State and local governments are the main financial supporters of public education in the United States. In 1991, 29.1 percent of state and local general outlays were used to provide educational services, making education the largest single area of state and local spending.[5]

Governments support education for a wide range of reasons.[6] The political desire to promote prosperity is perhaps one of the most important motivations for large public investments in education. K-12 and public university education prepare individuals for entry into the workforce. Arguably, the quality of a state's workforce, and therefore the quality of labor as a factor of production, is directly related to the quality of the education and training that is available; state and local governments may be viewed as social infrastructure providers that ensure that the workforce is sufficiently skilled to meet occupational requirements.

State and local governments also invest in education to promote equity. To some extent, there is an underlying belief in the United States that the full potential of each and every individual should be realized; education is seen as a basic mechanism for promoting that goal.

Another important motivation for public investment in education is competition. At the local, state, and national levels, there are political pressures to ensure that students are as capable as those of other local, state, or national jurisdictions. For example, at the national level, U.S. students are often compared with European and Japanese students under the assumption that America's role in the global economy will depend critically upon the ability of the nation's schools to adequately educate students.[7]

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[4] The provision of educational services, social services, and transportation infrastructure are described as "main functions" of state and local governments because large percentages of state and local revenue are used to provide those services. U.S. Bureau of the Census, p. 293.

[5] U.S. Bureau of the Census, p. 293.

[6] Robert Wilson, pp. 219-222.

[7] Robert Wilson, p. 221.

Finally, education is frequently described as a mechanism for promoting democracy and building individual character. Education may foster "good citizenship" by instilling a respect for democracy, and the institutions of democracy, as well as socializing individuals to provide commonalty across diverse ethnic and religious groups.

State and local governments are investing in educational technology to promote many of these goals.[8] For example, the State of Iowa is deploying a state-wide fiber-optic network that allows students and teachers in dispersed locations to interactively participate in televised classroom discussions.[9] Distance learning may improve the variety of opportunities available to students, including the possibility of enrolling in courses for advanced standing college credit, and promote equity by reducing geographic disparities in the allocation of educational resources.

Investment in information technology is seen as a mechanism for enhancing instruction, boosting test scores, and increasing student skills, for the purpose of easing student entry into colleges and the workforce.[10] For example, by using networked computers, students may learn skills that will transfer to the private sector where basic familiarity with networks and computers is increasingly important. The availability of novel technology may even increase the motivation of students[11], promoting student retention and higher graduation rates.

Finally, by making information technology available in schools to support electronic mail, record keeping, and the development of new course material, overall teacher productivity may also increase.[12]

As with any technology, the impact of telecommunications networks upon the quality of educational services is highly dependent upon how that technology is used. State and local governments, which are primary providers of public education, are deploying telecommunications networks with the intention of improving the quality of education to achieve a wide variety of

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[8] U.S. Congress, Office of Technology Assessment, pp. 57-70.

[9] This case is described in detail in chapter two.

[10] The effectiveness of computer based instruction has been assessed by many researchers, including Kulik and Kulik (see references).

[11] U.S. Congress, Office of Technology Assessment, pp. 65-66.

[12] U.S. Congress, Office of Technology Assessment, pp. 71-79.

underlying social and economic goals. In chapter two, examples of state networking initiatives to promote distance learning applications are considered.

1.2 Social Services

State and local governments are centrally responsible for the delivery of many social services. In 1991, 24.6 percent of state and local general outlays were used to provide social services, including welfare and health, making social services a major area of state and local spending.[13]

Governments provide social services for a wide variety of reasons, including to promote equity. The "New Deal" or "Great Society" view of the proper role for the public sector is that governments should be fundamentally responsible for ensuring that less fortunate individuals are adequately fed and housed, and receive basic health services. Vaccination programs, the provision of mental health facilities, and subsidies for hospitals are important examples of government efforts to promote public health. At a more pragmatic level, state and local governments may provide social services to promote political and economic stability and avoid the risks that may be posed by a large and severely impoverished underclass.

State and local governments utilize information technology, and telecommunications networks in particular, to provide social services. For example, information technology can be used to support the disbursement of welfare benefits by automating record keeping or using Automated Teller Machines. Hospitals can be interconnected using fiber-optic networks to allow physicians in remote locations to provide consulting services that ordinarily would require a special visit incurring significant travel costs; this application is referred to as telemedicine.[14]

Telecommunications technology may improve accessibility to social services by providing services at more locations over extended hours; improve the quality of services by providing services more quickly; provide more services due to the realization of efficiency gains; and lower costs by reducing the number of workers required to handle repetitious processing and service

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[13] U.S. Bureau of the Census, p. 293.

[14] Gould, p.8.

work that can be automated. However, the actual outcome of any investment in information technology, including for social services applications, will depend upon implementation strategies. In chapter two, examples of state networking initiatives to promote telemedicine applications are considered.

1.3 Transportation

State and local governments are centrally responsible for upgrading and maintaining transportation infrastructure. In 1991, 6.1 percent of state and local general outlays were used to provide highway infrastructure, making transportation a major area of state and local spending.[15]

State and local governments are motivated by a wide variety of goals to invest in transportation infrastructure. Transportation infrastructure investments may improve mobility, protect public safety, enhance energy efficiency, and reduce environmental hazards. These benefits may in turn promote worker productivity and facilitate economic development because transportation infrastructure is an important factor of production for industry.

States are investing in telecommunications technology to promote transportation infrastructure. Advances in digital computer and communications technology make possible new applications of information technology that may improve highway safety, reduce traffic congestion and vehicle emissions, and generally improve the economic productivity of the nation by enhancing mobility.[16] Intelligent Transportation Systems (ITS) integrate information technology into the design and operation of transportation networks for the purpose of achieving these goals.

The term ITS is inclusive of a wide variety of specialized applications including (1) Advanced Traffic Management Systems (ATMS), which provide centralized traffic control coordination capabilities; (2) Advanced Traveler Information Systems (ATIS), which provide information to travelers in the vehicle, home, or office; (3) Commercial Vehicle Operations (CVO), which support applications such as wireless electronic toll payments; (4) Advanced Vehicle Control Systems (AVCS), which provide services such as collision warning; and (5) Advanced Public

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[15] U.S. Bureau of the Census, p. 293.

[16] IVHS America, pp. I-2-I-6; U.S. Government Accounting Office, p. 3.

Transportation Systems (APTS), which provide services such as traveler information for public transit users.[17] There are numerous other applications that could be mentioned.

The extent to which these applications will actually promote mobility and other underlying goals is uncertain, and will depend upon specific implementation strategies. State and local governments are investing in ITS under the assumption that many of these new applications will produce tangible benefits for the public. Specific examples of ITS deployments are discussed in chapter three.

1.4 Network Ubiquity

Although state and local governments are investing heavily in information infrastructure, multi-agency implementation strategies are sometimes lacking. Networks within the same state or locality serving separate agencies may be duplicative and non-interoperable. These deployment problems are symptomatic of the characteristics of large and complex organizations in general, and state and local governments in particular.

Institutional and political considerations shape the field of forces influencing the behavior of public agencies.[18] These forces, which are both internal and external, will influence the procurement, deployment, management, and upgrading of public sector telecommunications networks. The cases presented in this thesis demonstrate that various institutional and political factors have encouraged the development of separate networks to serve specialized government networking requirements with little consideration for multi-agency resource sharing opportunities. As noted by the National Governors' Association, "The initial reaction from many organizations as they envision and plan to use telecommunications for purposes such as distance learning or law enforcement is that each needs its own network."[19]

The technological phenomena of convergence has obviated much of the technical rationale for developing separate networks. Emerging digital technology allows for the development of

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[17] IVHS America, pp. I-10-I-12.

[18] A general discussion about this topic is presented in Bureaucracy by James Q. Wilson (see references).

[19] National Governors' Association, p. 15.

ubiquitous networks that simultaneously serve applications in voice, video, and data communications, supplanting an earlier development model that segregated services by transmission medium: telephony over twisted pair copper lines, and video over coaxial cable. From this perspective, "bits are bits" without distinction based upon content or destination.[20] Accordingly, the development of technically efficient networks may require information technology deployment strategies that take into consideration the potential of ubiquitous networks to serve multi-agency networking requirements: "At a time when all levels of government are strapped for resources and business is pursuing increased productivity for each dollar expended, neither government nor business can afford multiple, redundant networks that execute roughly the same functions -- transmission of voice, data, and video -- but for different purposes."[21]

1.5 Thesis Overview

This thesis explores ongoing state and local government network deployments. A case study analysis of state and local broadband telecommunications network deployments provides the factual basis for considering institutional and political factors that may be inhibiting the development of ubiquitous networks that serve the broad telecommunications needs of state and local governments.

The following key questions are addressed in this thesis: Why are separate telecommunications networks being deployed for application areas such as ITS? How may deployment strategies that take into consideration multi-agency networking requirements be promoted?

Two case studies of state-wide telecommunications network deployments primarily serving applications in education and social services are considered in chapter two. The following initiatives are considered:

- Iowa Case Study: Iowa Communications Network
- North Carolina Case Study: North Carolina Information Highway

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[20] Technologies of Freedom by Ithiel de Sola Pool provides a detailed discussion on this topic (see references).

[21] National Governors' Association, p. 15.

Six case studies of fiber-optic network deployments primarily serving transportation applications are considered in chapter three. These include the following:

- Missouri Case Study: DTI Deployment
- Connecticut Case Study: I-95 Incident Management System
- Massachusetts Case Study: Central Artery / Tunnel Project
- Texas Case Study: San Antonio ATMS
- California Case Study: City of San Jose
- California Case Study: Bay Area Rapid Transit

The technological, political, and financial characteristics of all eight deployments are discussed in detail in chapters two and three to provide a full picture of each initiative.

In chapter four, the institutional and political factors influencing these deployments are discussed, with particular emphasis upon addressing the impediments to multi-agency deployment and utilization of telecommunications networks.

In chapter five, improved institutional arrangements intended to promote multi-agency initiatives are discussed. In particular, the roles of state information technology planning entities and the United States Department of Transportation (USDOT), which is centrally responsible for funding many ITS deployments, are considered.

Appendix A provides a primer on fiber-optic network technology and deployment for readers that are unfamiliar with the subject. Appendix B summarizes the acronyms used from time to time throughout this thesis. References are presented at the end of this document.

2.0 CASE STUDIES: EDUCATION AND SOCIAL SERVICES

In this chapter, case studies focusing on the deployment of the Iowa Communications Network (ICN) and the North Carolina Information Highway (NCIH) are presented. The cases were selected, in part, because they are widely publicized state networking initiatives for distance learning and telemedicine applications.[22]

The case studies were prepared in consultation with staff at the Volpe National Transportation Systems Center. Gary Ritter was particularly helpful, providing valuable directions and criticism. Phone interviews with representatives of various state agencies in Iowa and North Carolina were conducted during December 1995 and January 1996. All of the cases were independently revised and updated during the spring of 1996 to reflect new developments and specifically address the relationship between network deployments for education, social services, and ITS, and the issue of multi-agency deployment incentives.

2.1 Iowa Case Study: Iowa Communications Network

The state government of Iowa is presently deploying a broadband telecommunications network to serve the telecommunications needs of schools, hospitals, and government agencies. The broadband networking project is known as the Iowa Communications Network (ICN).

History

During the 1980-86 period, the state government of Iowa began experimenting with distance learning technology at community colleges using microwave and cable transmission.[23] However, serious planning for a state-wide, broadband network did not begin until the farm crisis of the mid-1980s, which placed great strains on the state's rural communities and provided the political impetus for a large scale program designed to promote the well being of the state.[24]

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[22] The cases differ from those presented in chapter three in that each network supports the telecommunications needs of multiple agencies rather than just the needs of a single government agency. This should not be taken as an indication that network deployments for education and social services are necessarily multi-agency initiatives.

[23] Kantrowitz, p. 55.

[24] Lewyn (no page number).

There were several preliminary planning efforts before the ICN was formally announced. In 1986, the Iowa Legislative Council conducted a study on the coordination of distance learning in the state. In 1987, the state legislature passed a bill that required Iowa Public TV (IPTV) to act as coordinator of distance learning and to develop a network design. The state legislature approved a formal Request For Proposal (RFP) in 1988 for development of a state-wide network. In September 1988, the IPTV issued the RFP. By November 1988, responses were received from AT&T, Teleconnect, and Northern Telecom. The low bidder for the project was Clark McLeod of Teleconnect in Cedar Rapids, Iowa.[25] A Notice of Intent to Award to Teleconnect was issued to McLeod. However, AT&T, which proposed a leased line network through a joint venture with U.S. West, "went before the State Executive Council to appeal the award of the bid," which was "later thrown out on a technicality."[26] This first RFP only involved distance learning applications.

A second RFP was issued in December 1989 but was latter withdrawn.[27] According to one analysis, the government "sought bids on a gold-plated system that would allow the state, rather than private companies, to control crucial switching operations" but latter "scrapped those bids finding them too high."[28] Telcos did not bid on the second RFP, apparently because they believed they would be constructing a system that would be in competition with their own infrastructure.[29]

A third RFP was issued in October 1990. The RFP was for a less elaborate system that could be built either "by sharing existing fiber-optic lines" or building a new network for the state.[30] Again, the telephone companies refused to bid on the system. In fact, they tried to kill the project by arguing on philosophical grounds that the state had no business owning a telecommunications network. Furthermore, they argued that if the state shifted its $7 million in telecommunications business to an owned network, rates for other consumers would necessarily

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[25] Teleconnect "later became part of Telecom USA and was sold to MCI." MFS Networking Technologies, p. 3.

[26] MFS Network Technologies, p. 3.

[27] MFS Network Technologies, p. 3.

[28] Fulton, p. 28.

[29] Fulton, p. 28.

[30] Fulton, p. 28.

increase.[31] None the less, the project moved forward, in large part because of the support of the governor and several key legislators.

The winning bid was made by MFS Network Technologies, which at the time was called Kiewit Network Technologies.[32] In April 1991, a construction contract for $73,761,798 was signed with Kiewit; construction began in October 1991. The state issued Certificates of Participation (COPs) to cover the costs of the project, which was divided into two phases, with a third phase to be bid upon at a later point in time.[33] Part I included interconnection of 15 community colleges, 3 regents institutions, and the State Capitol Complex.[34] In 1992, construction on Part II began which provided for interconnection of 84 more sites, establishing a point of presence in each county in Iowa. In May 1993, a second issuance of COPS was authorized to finance the increased costs associated with plans to add administrative traffic to the network. In total, the first two phases of the project cost $97.5 million, a considerable amount of money for the state.

Although the network was originally intended for distance learning services, in April 1994 the legislature "voted to allow hospitals and physician clinics, federal agencies, state judicial and corrections systems and the U.S. Post Office to use the network."[35] This effort was opposed by the Iowa Telephone Association, which wanted to limit the scope of the ICN project and prevent private health care providers from accessing the ICN and bypassing the networks of for-profit carriers.[36]

In August 1994, an RFP for Part III of the project was released. Part III provides for the interconnection of 478 K-12 schools and library sites, and approximately 60 national guard sites, to the network. The RFP allows multiple interests to participate in the deployment. Subcontractors are presently installing fiber; sixty percent of the links are being put in by private

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[31] Lewyn (no page number).

[32] The bid was for $73.7 million. Fulton, p. 28.

[33] MFS Network Technologies, p. 3.

[34] Legislative history provided by ICN staff.

[35] MFS Network Technologies, p. 4.

[36] As recently as June 1995, the Iowa Telephone Association expressed serious disagreement with the state's policy of owning network capacity. King, p.7.

carriers that will own, operate, and maintain the interconnections, and accordingly will provide leased services to end-user sites; the other forty percent of the fiber is being installed as dark fiber by contractors that will turn the fiber over to the state which will handle operations and maintenance responsibilities. During the 1995 session, the "legislature began its review of Part III proposals and agreed to a $94.7 million plan to connect 474 Part III sites using privately leased lines."[37] The decision to use leased services was in part motivated by the desire to avoid further political conflict regarding the state's role in network deployment.

Relationship to Intelligent Transportation Systems

At this time the ICN is not being used for ITS services. However, the Iowa Department of Transportation (IDOT) is a major user of the ICN for data networking applications and long-distance telephony services; IDOT has many locations throughout the state. IDOT staff are presently not aware of any intention to use the ICN for ITS applications in the future.

Technology

The ICN is a Synchronous Optical Network (SONET). The network consists of three main fiber rings, with a star topology network superimposed, interconnecting 15 switching centers. The capacity of this portion of the network, which corresponds with Part I of the previously described deployment, is equivalent to 48 DS3s.[38]

Part II of the network involved interconnecting each main switching center to end-user sites; Part II of the network has a capacity of 12 DS3s. All of the fiber in the system is single-mode.[39] In total, about 2,800 miles of fiber were deployed for the project. Part III sites will be interconnected to the ICN using links with 3 DS3 capacity.

The system also includes points of access for satellite uplinks and downlinks and terrestrial microwave. The system is interconnected to the Internet and can interconnect to IXCs.

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[37] Legislative history provided by ICN staff.

[38] The capacity of a DS3 is approximately 45 Mbps.

[39] Multimode fiber is less desirable than single-mode fiber because light dispersion phenomena are more pronounced, thereby increasing the need for intermediate repeaters (see appendix A).

Switching for video and voice/data are separated to ensure a desired quality of service. The system provides broadcast quality video for education applications and "instantaneous switching."[40] System reliability for video transmission is only 99% because alternate routing schemes have not been implemented. However, ICN staff are presently looking into this issue. For voice and data services, the reliability of the network is comparable to the reliability of the Public Switched Telephone Network (PSTN). ICN system components are backed up with emergency power supplies. A $500,000 grant provided by the Federal Emergency Management Administration (FEMA) "enabled the state to equip each site with standby generators that have a 14 day fuel supply, redundant DC power supply and battery backup to assure operation during an emergency, disaster or common power outage."[41]

At this time, operations and maintenance is handled by MWR Telecom staff who work under the supervision of ICN staff. The decision to outsource operations and maintenance dates back to 1990.[42]

Cost

The deployment cost for Parts I, II, and III is about $200 million. MWR Telecom is working under a yearly maintenance contract worth about $3 million per year. However, operations and maintenance expenses are likely to increase as further sites are interconnected to the network. The maintenance costs are expected to double after all of the Part III sites go on-line.

The end-user cost for video service at educational institutions is $5 per hour per site. For example, interconnecting two sites costs $10 per hour. Users pay $40 per hour per site for non-educational applications such as telemedicine. According to some estimates, comparable rates for leased services from the private sector would be about $300-400 per hour per site.[43]

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[40] Conversation with Bob McWithey, Director of Engineering, ICN, January 5, 1996.

[41] MFS Network Technologies, p. 2.

[42] During the 1994 gubernatorial campaign, Attorney General Bonnie Campbell used a campaign ad against incumbent Governor Terry Branstad arguing that he had given "millions in questionable non-bid contracts to campaign contributors." The remark was an apparent reference to the decision to give MWR Telecom the operations and maintenance contract. Fogarty (no page number).

[43] MFS Network Technologies, p. 8.

The state anticipates that it will realize important cost savings from the network. For example, the state pays $750 per trip to transport sick inmates and their guards to medical facilities.[44] However, the cost of transmitting data over the network is just $40 per hour per site. "Since the program started in 1990, the state has saved $211,000 on treatment, while spending only $100,000 on the network."[45] Other examples of cost savings are also cited: "One community college scheduled 50 meetings over the network in four month's time. In travel time alone, it reported a savings of twenty 40-hour work weeks. In addition, it saved $2,300 in mileage expenses."[46] The state expects to realize savings on the costs of telephony service: "government telephone traffic on the ICN costs 7 to 13 cents a minute, compared to the up to 25 cents a minute charge of traditional long distance carriers."[47]

Future

During the 1995 session the legislature established the 461 Task Force to conduct a study of future options for the ICN. Generally, the 461 Task Force recommended "continuing operations of the ICN as a state-wide fiber-optic network for use by authorized users."[48] Furthermore, the task force recommended "that no additional private users be added to the Network" and that the network not be sold, leased, or converted to a utility in the near future.[49]

Although the project was at times very controversial, public opinion toward the ICN may be improving.[50] Furthermore, the local telephone companies seem less upset than they were before the project started because demand for telecommunications services has actually increased since the inception of the project, according to ICN staff.

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[44] Lewyn (no page number).

[45] Lewyn (no page number).

[46] MFS Network Technologies, p. 8.

[47] MFS Network Technologies, p. 8.

[48] Iowa law allows the following types of users on the network: all accredited K-12 school districts and private schools; all accredited public and private colleges and technical education institutions; all state agencies; all federal agencies; the United States Postal Service; hospitals and physician clinics; and public libraries.

[49] State of Iowa, Iowa Telecommunications and Technology Commission (no page number).

[50] Wexler (no page number).

Future prospects for upgrading to ATM are being considered by ICN staff. At this time, an ATM testbed is being established. In 1994, Tony Crandall of the ICN estimated that full scale implementation of ATM would be about three to five years away.[51]

Lessons

The history of the ICN was in many respects controversial. Taxpayers were skeptical about the costs and private telephone companies were strongly opposed to the development of a state-owned network. The political controversy surrounding the state's initial decision to own rather than lease telecommunications capacity was a major obstacle to the progress of the initiative. Eventually, a less ambitious approach was adopted for Part III of the network deployment, which provided for the leased line access alternative. The continued progress of the state in developing the ICN was centrally dependent upon high level political support from the governor and the state legislature which promoted multi-agency network access and use, including providing access to health care providers, federal agencies, and the state criminal justice system.

Thus, two main lessons may be drawn from the ICN deployment. First, government network deployment initiatives can become politicized, potentially influencing both the scope of deployment and the institutional arrangements selected for deployment. Second, high level political support can favorably influence both the scope of deployment and the level of multi-agency participation.

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[51] Wexler (no page number).

2.2 North Carolina Case Study: North Carolina Information Highway

The state government of North Carolina is presently developing a state-wide, broadband network to serve the telecommunications needs of schools, hospitals, the criminal justice system, and private businesses. Specifically, the state envisions that broadband telecommunications services will facilitate applications such as distance learning, telemedicine, and remote parole hearings. The project is premised upon the assumption that the state can leverage its buying power to promote private sector deployment of information infrastructure which in turn will promote telecommunications intensive industries. As noted in a report by Deloitte & Touche, "The North Carolina region has over one-third of its current employment base in industries which can be defined as telecommunications-intensive, and the state's reliance upon telecommunications-intensive industries is expected to increase over the next several decades to the point where nearly one-half of the future employment base in North Carolina could be generated by telecommunications-intensive sectors of the economy."[52] The state's most recent initiative to promote the deployment of broadband telecommunications infrastructure is known as the North Carolina Information Highway (NCIH).

History

The history of the NCIH extends back well over a decade to earlier initiatives. During the early 1980s, the North Carolina General Assembly established an Information Technology Council to address technology issues; this organization was the predecessor to the Information Resources Management Commission which is now centrally responsible for state government information technology issues including the development of the NCIH.[53]

In March 1991, Governor James G. Martin adopted Executive Order 136 which established the North Carolina Advisory Council on Telecommunications in Education. The mandate of the council was to "develop a long-range plan for the use of technology in public schools, universities,

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[52] Deloitte & Touche LLP, p. I-3.

[53] State of North Carolina, p. 11.

community colleges, homes, and prisons across the state."[54] From 1991 to 1993 the state pursued pilot projects in networking including CONCERT (now called NC-REN), Vision Carolina, IMPACT North Carolina, VISTAnet, and Community Link. These projects included test trials of distance learning and telemedicine applications.[55]

In December 1992, the Government Performance Audit Committee (GPAC) released a Performance Audit of Information Technology and Telecommunications and found that the state should consolidate its networks, provide "bandwidth on demand," and investigate options involving new broadband technology.[56] At the same time, the office of the State Controller, working independently, requested proposals to be submitted from three major telephone companies (Southern Bell, GTE, and Carolina Telephone) for construction of a state-wide network; this approach avoided the political difficulties associated with an open bidding process which could have potentially provided for a winning non-telco alternative.[57] Proposals were submitted in April of 1992 and final design and pricing was determined in October 1992.[58] This network plan came to be know as the North Carolina Information Highway (NCIH). The projected date for initial operation of the NCIH was set for June 1994.

Governor James Hunt, elected in November 1992, placed a high priority on moving the NCIH project forward. The project is headed by Jane Patterson, the Governor's Advisor for Policy, Budget, and Technology.[59] The project was formally announced on May 10, 1993 in a "joint press conference with representatives of the three telephone companies."[60] Thus, in all respects, the state enjoyed an amicable relationship with the local telcos. An NCIH Steering Committee, on which Patterson served as Chair, identified about 3,400 sites for interconnection to the NCIH based upon criteria that it devised. According to Patterson, the "Steering Committee has

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[54] State of North Carolina, p. 11.

[55] State of North Carolina, pp. 65-66.

[56] State of North Carolina, p. 12.

[57] "State government in North Carolina has the ability through statutes and regulations to upgrade its network without the mechanism of bidding." Patterson in 1995, p. 135.

[58] State of North Carolina, p. 12.

[59] Patterson in 1995, p. 134.

[60] State of North Carolina, pp. 12-13.

provided strategic direction and overall coordination" for the project.[61] The project was intentionally designed to serve multi-agency requirements to ensure the project would have a broad base of political support.

The NCIH project was to be implemented in two phases. Phase I was to involve interconnecting 100-400 sites over a 15-18 month period beginning in June 1994 with Phase II covering the remaining sites by the year 2003. However, after an initial 106 sites were announced in January 1994, the legislature modified the NCIH project implementation schedule; only 34 sites -- mostly schools -- were online as of August 1994.[62] As of April 1996, approximately 115 sites were operational.[63]

Relationship to Intelligent Transportation Systems

At this time, the NCIH is not being used for ITS services. According to staff with the North Carolina Department of Transportation, the potential interrelationships between the NCIH and ITS are just beginning to be considered. However, no formal plans are established or being developed.

Technology

The initial design of the NCIH involves 10 Fujitsu FETEX-150 Broadband ATM switches and two AT&T ATM switches.[64] The state first began experimenting with running ATM over a SONET network in 1989 with the VISTAnet project which was selected by the Corporation for National Research Initiatives (CNRI) as a gigabit testbed.[65]

By March 1995, a total of 10 Fujitsu switches were deployed (five by Bell South, three by Carolina Telephone, and two by GTE). The configuration of the system allows "up to 64 user/network interface ports capable of running at 155 Mb/s (SONET OC-3c)" yielding a

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[61] Patterson in 1995, p. 134.

[62] State of North Carolina, p. 13.

[63] These sites provide video services. Approximately on dozen other sites use the NCIH for data services.

[64] "ATM Cell Relay is a connection oriented service that provides high-speed and low delay transfer of ATM cells" Grovenstein, p. 18.

[65] Grovenstein, p. 18.

bandwidth of 9.6 Gbps.[66] Switches, available in the future, will provide a total capacity of as much as 160 Gbps.[67] The 10 switches are located in the following way: (1) Bell South -- Asheville, Charlotte, Greensboro, Raleigh, and Wilmington; (2) Carolina Telephone -- Greenville, Fayetteville and Hickory; and (3) GTE -- Durham and Research Triangle Park.[68]

The network will also include Broadband Remote Line Concentrators (BRLCs) which will be deployed in some communities: "These BRLCs serve multiple sites in communities and support concentration in the umbilical backbone to the host ATM switches."[69] BRLCs can be upgraded to ATM switches in the future.

Fiber deployment was not a critical issue for the NCIH project because existing installed fiber was readily available to the telephone companies. However, single-mode fiber was deployed to each site from nearby nodes.[70] SONET links interconnect the IXCs and ATM switches. Initially "the 155-Mb/s OC-3c rate will be used between each customer site and the central office, with the capability to grow to 622 Mb/s, 2.4 Gb/s, or even higher access rates as needed in the future."[71]

Although reliability information is not readily available, the system is part of the public switched network and is therefore likely to have a similar reliability. All operations and maintenance of the network is handled by the three telephone companies. End-users of the network, however, are responsible for on-premises equipment.

Cost

The financial costs of network infrastructure deployment are completely absorbed by the three telephone companies. End-users of the network, including schools and hospitals, are responsible for initial and ongoing costs associated with on-premises equipment, according to

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[66] State of North Carolina, pp. 24-25.
[67] State of North Carolina, p. 25.
[68] Patterson in 1995, p. 132.
[69] Patterson in 1995, p. 132.
[70] Grovenstein, p. 19.
[71] Grovenstein, p. 18.

present plans.[72] However, there is some question whether end-users such as public schools will be able to afford ongoing costs. The state claims to serve as the "anchor tenant" providing demand for services which in turn justifies the risks associated with network deployment from the perspective of Bell South, Carolina Telephone, and GTE:[73] "The companies plan to recoup their investment through monthly charges and usage fees paid by the state and eventual use of the network by commercial customers under general tariffs."[74] The cost to the private sector to build the network over the next 10 years is estimated at $160 million.[75]

The North Carolina Utilities Commission is responsible for setting leasing rates for the NCIH. The startup costs for each site "will be approximately $100,000 and the monthly on-line costs per site are currently set at $4,000 for the baseline usage of 64 hours of video."[76] However, future leasing costs may decline.[77]

State funding for the NCIH was originally $4.1 million for fiscal year 1993-94. In 1994, before the initial appropriation was used, the legislature became concerned that the funds would be used to meet ongoing costs of the network rather than initial start-up costs for individual sites. At the same time that the $4.1 million appropriation was being reconsidered, the legislature was also considering a $5.3 million appropriation for fiscal year 1994-95. Eventually, the original $4.1 million appropriation was rescinded by the General Assembly which instead appropriated $7 million for one-time grants to sites.

According to a March 1995 state audit report, $19,650,875 had been spent to date on the NCIH, which is small compared with the large investment in the ICN.[78] Future costs will obviously depend upon the projected number of sites that are eventually connected to the network.

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[72] "Base rates are the same for all sites with no penalties to be incurred for remote sites or long distances between sending and receiving locations" State of North Carolina, p. 20.

[73] State of North Carolina, p. 20.

[74] State of North Carolina, p. 41.

[75] State of North Carolina, p. 41.

[76] State of North Carolina, p. 54.

[77] "For example, Motion Picture Experts Group (MPEG-2) video codecs operating at about 6 Mb/s are expected to become available in 1995. This will provide good video quality at a much lower bandwidth than the 45 Mb/s used initially. Since the usage component of the service is based on a price-per-gigacell, reducing the bandwidth reserved per connection from 45 to 6 Mb/s will result in a much lower cost per hour of video connect time. It will also reduce the amount of bandwidth that the customer must purchase from an IC for interLATA communications." Grovenstein, p. 20.

[78] The amount spent on the NCIH includes funding from grants. State of North Carolina, p. 57.

Table 2.1 shows yearly forecasts for the total number of sites on the network as estimated by NCIH staff in 1993, 1994, and 1995. The data clearly shows that projections are being rapidly revised downward due, in part, to the reluctance of the legislature to provide funds.

TABLE 2.1 - NCIH SITE FORECASTS[79]

Year	1993 (Original)	March 1994*	January 1995**
1995	466	853	143
1996	1332	1282	300
1997	3158	1679	500
1998	3348	1882	750
1999	3392	2018	1100
2000	3432	2322	1500
2001	3472	2616	2000
2002	3472	2894	2600
2003	3472	3424	3424

* revised forecast based upon Deloitte & Touche Vendor Cost Review

** revised forecast based upon Office of State Auditor Performance Report

The total projected costs for the network by 2003, assuming the most recent deployment scenario, is roughly $1 billion of which $300 million is for "fiber access and usage charges" and $130 million for "interlata charges."[80] Thus ongoing costs could be very large requiring a significant investment by the state.

In part, the declining deployment projections may be a consequence of the deployment strategy selected by the governor. By adopting a leased services approach rather than an owned

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[79] State of North Carolina, p. 46.

[80] Note that the full $1 billion cost would not necessarily be incurred by the State of North Carolina. State of North Carolina, p. 60.

network approach, the state successfully avoided the potential political opposition of the local telcos and the difficulties associated with obtaining a large up-front budget expenditure. However, the drawback is that the long-term leasing costs are expensive and pose a political obstacle because the legislature seems unwilling to provide funds to meet ongoing costs.

The state commissioned Deloitte & Touche to review pricing and determined that "...the rates proposed by the LECs remain fair and reasonable considering the nature of this project, the associated risk to the LEC if the NCIH project does not generate significant commercial use (i.e., non-state-government users) and the respective cost structures of the LECs."[81]

Future

The large projected funding requirements for the NCIH, and the apparent reluctance of the legislature to provide appropriations, suggests that the long-term viability of the NCIH may be in question. The project has received a great deal of attention in the media. However, the level of attention that it has received may not be commensurate with the actual level of commitment to the project. As noted in one media account, the NCIH is more like a "computer cow path" than an information highway because of the slow pace of development.[82] However, as noted earlier, well over 100 sites providing real-time video conferencing capabilities are now operational. Despite difficulties, the NCIH project appears to be moving forward.

Lessons

The case suggests that alternative institutional arrangements for promoting network deployment emphasizing private sector ownership may be useful for avoiding political obstacles associated with network deployment. However, there are also disadvantages. Ongoing leasing costs may be prohibitive and, according to some estimates, leasing may be more expensive in the long-term than owning. Thus, the deployment approach succeeds at avoiding near-term political conflict, but incurs the disadvantage of longer-term budget battles to cover ongoing costs.

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[81] Deloitte & Touche LLP, p. I-1.
[82] Business North Carolina, p. 10.

Both the ICN and NCIH case studies demonstrate that network deployments that require significant budget allocations are likely to be scrutinized by the public, state legislators, and special interests. Other large-scale, well publicized networking initiatives are likely to be similarly scrutinized.

3.0 CASE STUDIES: TRANSPORTATION

A total of six case studies focusing on the deployment of fiber-optic networks for Intelligent Transportation Systems (ITS) are presented in this chapter. The cases presented here include (1) the Missouri Highway and Transportation Department (MHTD) state-wide ITS deployment; (2) the Connecticut Department of Transportation (ConnDOT) incident management system; (3) the Massachusetts Highway Department (MHD) Central Artery/Tunnel (CA/T) project; (4) the Texas Department of Transportation (TXDOT) - San Antonio District Advanced Traffic Management System; (5) the City of San Jose Department of Streets and Traffic (SJDST) Traffic Signal Management Project and Motorist Information Systems Project; and (6) the Bay Area Rapid Transit (BART) Telesystem. The cases were selected to demonstrate the wide range of possible deployment strategies being adopted by transportation agencies rather than to serve as a representative sample.

Each study was prepared in consultation with staff at the Volpe National Transportation Systems Center. Gary Ritter was particularly helpful, providing valuable directions and criticism. Phone interviews with representatives of various transportation agencies, conducted during March and April of 1995, provided the primary basis for the six case studies. The cases were originally presented at a unique meeting of officials from public transportation agencies and private telecommunications service providers at the "Intelligent Transportation Systems Infrastructure Forum" hosted by the Volpe National Transportation Systems Center in Cambridge, Massachusetts on April 27, 1995. The author and Daniel Roos presented a paper based upon the case studies at a unique day long workshop on "Intelligent Transportation Systems and the National Information Infrastructure" at Harvard University on July 13, 1995. A revised version of the paper will be published as a chapter in a forthcoming book from MIT Press (see references). All of the cases were independently revised and updated during the spring of 1996 to reflect new developments and specifically address the relationship between network deployments for distance learning, telemedicine, and ITS, and the issue of multi-agency deployment incentives.

3.1 Missouri Case Study: DTI Deployment

The Missouri Highway and Transportation Department (MHTD) is deploying ITS statewide to support the needs of metropolitan St. Louis, metropolitan Kansas City, and rural Missouri. The state's goals for ITS deployment include increased vehicle speeds, improved air quality, reduced energy consumption, and improved safety. The services that will be made available are principally in the areas of rural and urban highway traffic management and traveler information. MHTD will utilize a fiber-optic communications network to support new applications.

Missouri's future ITS system will include components such as changeable message signs, detector stations, ramp meters, and real-time video surveillance cameras, as well as computers and workstations for a central traffic operations and information center. The estimated total cost of deployment of ITS in the St. Louis metropolitan region is expected to be about $95 million. Statewide costs are not yet available. Missouri's strategy is to deploy incrementally and build support for ITS with early successes.

According to reports prepared by Edwards and Kelcey Inc., a fiber backbone was the only sensible option to support the communications needs of a regional ITS deployment.[83] Planning documents note that of the various transmission media available, only coaxial cable, microwave, and fiber are capable of supporting broadband services. Planners quickly ruled out coax and microwave, noting that fiber is more reliable and can be upgraded to higher capacity. In addition, microwave is not particularly desirable because antennas at each site would be aesthetically unacceptable and would be difficult to install since they must be in line of sight of one another.

When planning studies by Edwards and Kelcey reported that the cost for the fiber system in the St. Louis metropolitan area alone would be an estimated $22 million, MHTD immediately began looking for alternatives to direct fiber network procurement. Planners noted that leasing costs were astronomical and that there was a fear that leasing costs would increase.[84] However, it was generally believed that system reliability could best be ensured by using a privately owned network because the state does not have the expertise to perform operations and maintenance and

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[83] Technical Memoranda, 1993; Final Report, 1994.

[84] In an interview with a project worker, past increases in leasing costs for twisted pair were cited.

because the private sector has a financial interest in ensuring the viability of the network based upon the revenue potential of the system.

In 1993 MHTD began exploring the possibility of leveraging its right-of-way to obtain communications capacity. The MHTD decision to leverage right-of-way for communications capacity was in part spurred by the national interest in fiber-optic network deployment at the time. Planners believed that the private sector was moving rapidly and that the state should act quickly while there was substantial demand for access to the state's right-of-way. Many private sector businesses expressed an interest in accessing the right-of-way. In the fall of 1993, 22 cable and telephone companies attended a pre-bid conference for a Request For Proposal (RFP) that the state was drafting to select an appropriate contractor. Top management at MHTD, the State Highway Commission, and the U.S. Department of Transportation (USDOT) approved the RFP; approval from USDOT was required because utilities are permitted to access interstate right-of-way only on a case by case basis. The RFP was for provision of fiber communications capacity throughout the St. Louis metropolitan region, but allowed bidders to propose broader deployments including Kansas City and rural portions of the state. Early in the spring of 1994 proposals were submitted, and Digital Teleport Incorporated (DTI) was selected.

In exchange for access to the state's right-of-way, DTI is deploying fiber along 1,250 miles of state right-of-way and will provide MHTD with three T1 (1.5 Mbps) lines at each of 300-400 network nodes throughout Missouri.[85] As of April 1996 the state was considering extending the contract to cover an additional 450 miles of state right-of-way.[86] The state will pay nothing for access to the system. DTI will be fully responsible for all operations and maintenance, while MHTD will be responsible for building and maintaining all system components that it interconnects to each network node. MHTD is confident that the system will provide sufficient communications capacity for ITS needs.[87] The total cost to DTI, including controllers, is estimated to be about $45

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[85] The contract formally states that MHTD will receive six fibers but according to MHTD staff, DTI will provide T1 connections as described.

[86] According to MHTD staff, the segment could provide an additional 50-60 network nodes.

[87] The April 1994 Final Report states that "The type of media used for communication from the nodes to the field equipment can vary, depending upon the specific situation requirements. For instance, the media could be fiber optic, copper twisted wire pair, spread spectrum radio, microwave, or other appropriate technology.

million state-wide, of which about $22 million will be spent on the communications system in the St. Louis metropolitan area.

The project is divided into three phases. The St. Louis and Kansas City metropolitan areas will be completed by 1996 and 1997 respectively, and the rural interstate portion will be completed by 1998.

DTI's network is based upon the SONET standard to ensure that systems operated by other agencies in the region can be interconnected.[88] The fiber network will have a main backbone with OC-12 capacity (622 Mbps). OC-1, OC-3, T1, and T3 streams can be multiplexed onto the system. DTI is using a Japanese company as the system vendor for the project.[89] The contract with DTI grants exclusive rights and privileges that prevent the MHTD from providing preferential right-of-way access for alternative fiber-optic deployments or utilizing the MHTD's capacity for non-ITS applications. The Missouri Public Services Commission refused to allow the state to obtain communications capacity under a more lenient arrangement for regulatory reasons.

MHTD briefly considered building a network to serve the broader communications needs of government, but soon rejected the idea for a combination of reasons. First, MHTD was concerned about potential opposition by telecommunications companies. Second, MHTD staff believed that waiting for sufficiently broad consensus to form for such an ambitious project might allow the brief window of opportunity to leverage state right-of-way to be missed.[90] Third, the Public Services Commission stated its "opposition" to having the state compete as an unregulated utility against regulated utilities; the practical implications of this opposition were not determined by MHTD staff. Thus the MHTD case demonstrates that a wide range of institutional and political factors may significantly influence the scope of state government telecommunications network deployment.

The media could even be the re-use of existing interconnect cable from an existing signal system. The recommended communications media for connection of field equipment is fiber optic cable." (section 4, p.31).

[88] This is particularly important for the St. Louis metropolitan area, which includes areas of both Missouri and Illinois.

[89] There was some difficulty obtaining the vendor name from DTI.

[90] Whether or not there was only a "brief window of opportunity" is uncertain in the opinion of the author.

3.2 Connecticut Case Study: I-95 Incident Management System

The Connecticut Department of Transportation (ConnDOT) is presently deploying an incident management system along the I-95 corridor from the New York State border east through Branford, Connecticut. The corridor has above-average congestion problems -- caused in part by highway incidents such as traffic incidents -- which can be reduced using incident management techniques. The primary goal of the system is to reduce the time required to detect, verify, and respond to an accident. High-resolution video surveillance cameras will allow incidents to be monitored from an operations center which will then provide traveler information, such as alternate route recommendations, to motorists.

Construction of the incident management system began in October 1993 and is mostly complete. The system includes 91 cameras and 217 radar detectors, which service 56 miles of roadway. A fiber network was installed along I-95 and additional fiber loops are in place for future expansion.

Parsons Brinckerhoff Quade & Douglas, Inc., of Glastonbury, Connecticut, was hired in 1992 to research and design the incident management system, taking into consideration the technical tradeoffs of various communications system designs. Based upon their recommendations, ConnDOT decided to deploy a fiber network because of its immunity to electromagnetic interference, broadband and real-time service capabilities for video surveillance applications, and relatively small cable diameter, which conserves conduit space.

A Request For Proposal (RFP) for the system was released in late 1992/early 1993 that provided for individual contractors to install conduit for each of three contiguous sections of I-95. ConnDOT believed that a single contractor would not be capable of deploying the conduit quickly enough to meet the Department's goals. The contract for the middle portion of highway included pulling the fiber and installing the electronics for the full 56-mile deployment. Rizo Electric was awarded the contract to install the middle section of conduit and ITS components, including the communications system. Ducci Electric and Semec handled the remaining conduit installation contracts.

The full cost of the deployment, including conduit, is about $26 million, of which 80 percent is funded by the U.S. Department of Transportation (USDOT) Federal Highway Administration (FHWA).

The conduit is presently in place and Rizo Electric is nearing completion of the incident management system.[91] The first two years of operations and maintenance will be handled by Rizo Electric, after which time ConnDOT will consider continuing outsourcing operations and maintenance. SmartRoutes, Inc. is under a two year contract to operate the traffic control center.[92]

The decision to own the fiber communications system rather than lease capacity was made within ConnDOT and was supported by the Department's Commissioner. No study was performed to determine the cost-effectiveness of each option. Officials at ConnDOT simply wanted an owned system because the Department's "philosophy" is to own the infrastructure required to carry out its mission. The one decision factor identified by staff was that there was some concern that obtaining services through a leasing contract would take a relatively long period of time to arrange because private carriers did not have appropriate facilities available. However, ConnDOT did not fully investigate the extent to which Southern New England Telephone (SNET) or another telecommunications service provider could have offered sufficient communications capacity. Furthermore, no reliability study was performed to ascertain whether leasing, owning, or outsourcing would be the most effective strategy. None the less, the decision to build an owned network did not lead to political conflict with SNET, perhaps because the company did not perceive this to be a missed business opportunity.

In the case, ConnDOT planners simply did not consider the potential for using the network to provide communications services to other state agencies. Furthermore, although several private sector organizations have expressed an interest in obtaining access to the conduit deployed by ConnDOT, no public agencies have expressed an interest in obtaining capacity. Thus the case demonstrates that sometimes the issue of sharing network infrastructure simply does not arise.

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[91] According to ConnDOT staff, as of April 1996 the system was mostly complete, with work remaining on the system's software.

[92] Note that ConnDOT staff are in the operations center monitoring the work.

3.3 Massachusetts Case Study: Central Artery / Tunnel Project

The Central Artery/Tunnel (CA/T) is a multi-billion-dollar project to replace Boston's elevated Central Artery (I-93) with a subsurface expressway and to construct a third harbor tunnel to Logan International Airport accessible from the Massachusetts Turnpike (I-90). The CA/T comprises 7.5 miles of roadway, most of which will be covered or submerged. The project is currently administered by CA/T management under the Massachusetts Highway Department (MHD). However, the state is considering transferring control of the CA/T system to the Massachusetts Turnpike Authority (MTA) to allow the project to be funded with toll revenues.[93]

The CA/T project includes the deployment of a fiber-optic network to support monitoring and control of speed-limit and lane-change signs, variable message signs, closed circuit television (CCTV) cameras, and other ITS components.

Essential characteristics for the communications system were identified in a 1990 concept report prepared by Bechtel/Parsons Brinckerhoff, including the need for highly reliable voice-, video-, and data communications.[94] The report concluded that the communications system should rely upon a fiber-optic backbone and that the state should adopt a policy "on the selling or leasing of publicly funded spare conduit space and spare cable capacity to private revenue producing companies."[95] The Bechtel/Parsons Brinckerhoff report was reviewed and endorsed by at least three entities: CA/T management, the Massachusetts Highway Department (MHD), and the U.S. Department of Transportation (USDOT). This process involved the design managers and project directors for the state and within CA/T management. MHD decided to build and maintain its own fiber-optic network.[96] At this time MHD has no plans to lease reserve communications capacity to the private sector.

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[93] The MTA operates and maintains the Massachusetts Turnpike and other facilities. Pending legislation in the Massachusetts legislature would give the MTA authority over the CA/T system (see LeHigh and Phillips).

[94] Bechtel/Parsons Brinckerhoff, "Central Artery (I-93)/Tunnel (I-90) Project: Communications Systems" (see references).

[95] Bechtel/Parsons Brinckerhoff, pp. 9-10.

[96] The key factors influencing the state's decision to buy rather than lease a fiber-optic network were cost, reliability, and availability of leased infrastructure; planners also considered operations and maintenance issues. According to project planners, there was no cost alternative to procurement in 1990 and there probably is not one today. Video applications for the network require broadband transmission capacity,

Project planners wanted to minimize potential disturbances to the communications system induced by electromagnetic interference and other physical and environmental phenomena. There was a clear recognition that standardized signal transmission technologies should be adopted to ensure network compatibility, extensibility, and reliability. These functional needs led to the selection of a fiber-optic system for the communications backbone. Alternatives, including microwave, twisted pair copper wire, and coaxial cable, were also considered. Each medium was rated on the basis of coordination, integration, compatibility, flexibility, and maintenance/service ability. In each category, fiber was determined to be superior. Specifically, fiber does not require intermediate repeaters and is less susceptible to electromagnetic interference than alternative media. Moreover, the relatively small cable diameter conserves conduit space, which is limited and may be required for future applications. Fiber is also capable of supporting a wide range of delivery needs, including voice-, video-, and data transmissions.[97]

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which is typically very expensive to lease. Cost analyses carried out by technical and estimating staff showed that procurement was the only viable alternative for the state, since leasing could have been about five times more expensive. (However, in an interview, project planners were unable to identify a formal project report in which system costs were identified for various options.) Aggregate operations and maintenance costs for the entire CA/T project were repeatedly reviewed by the Project Director and will continue to be reviewed on a periodic basis. The RFP for the communications system included life-cycle costs for the first five years of system operation and maintenance to encourage Perini-Powell to consider operations and maintenance costs in designing the communications system.

System reliability was also a critical decision factor. The 1990 concept report clearly states the need for a highly reliable communications system. In an interview, project planners expressed doubts about the ability of the private sector to ensure sufficient reliability using the public switched network because communications service providers have multiple customers and therefore may not prioritize CA/T communications. Moreover, public switched network upgrades unrelated to the CA/T system could cause network failures that would otherwise not occur if the system were wholly owned and operated by the state. Although service contracts can be arranged with system reliability clauses designed to assure the buyer that network failure will not occur, state planners suggested that these clauses may be useless in preventing outages. In an interview, project engineers suggested that the required mean-time-before failure of the system needs to be five years or greater, but that in the public switched network it is typically less than one year. (In this context, mean time before failure refers to critical, system-wide failure where the network does not recover within a specified period of time.) According to project planners, when the concept report was prepared in 1990 private companies were just getting started with fiber deployments in the area and may not have been well positioned to meet the communications needs of the CA/T system. (NYNEX, MFS, and Teleport are major telecommunications service providers in the Boston area. NYNEX is the main local access provider in Massachusetts; MFS and Teleport are competitive access providers (CAPs) that compete with NYNEX in the region.)

[97] A fiber optic network could also be integrated into the MTA's communications system to provide additional capacity and redundancy and contribute to the development of a seamless state-wide network for transportation communications.

In September 1993 an RFP was issued for the third harbor tunnel portion of the communications system, which would be owned and eventually operated by MHD. The RFP required the contractor to have initial responsibility for operating the system. A single RFP was utilized to keep costs down and focus accountability. The RFP covered monitoring and controlling speed-limit and lane-change signs, variable message signs, emergency telephones, a closed-circuit television system, heat detection and fire alarms, and the control system for ventilation fans. NYNEX, the regional telephone company, did not bid in this phase of the project, presumably because the scope was significantly broader than its established line of business.[98]

Perini-Powell was selected in January 1994 as the general contractor for the communications system development. The contract required Perini-Powell to utilize off-the-shelf equipment to satisfy all of the system's requirements in order to avoid unforeseen problems, such as technical incompatibilities. The contractor will receive $8.6 million for installing the multi- and single-mode fiber network.[99] A second RFP will be issued in 1998 for the remaining portion of the communications system; the fiber backbone for the second phase is expected to cost about $11 million. The total CA/T single-mode backbone will be approximately 7.2 miles long when completed in 2001 and will cost about $20 million.[100] The CA/T fiber network is based upon the SONET standard to ensure ease of future upgrades and system maintenance. Network capacity is OC-3 or 155 Mbps. Perini-Powell is using AT&T as the system vendor for the project. There are no state-wide standards for the deployment of fiber-optic technology; essentially, the CA/T will

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[98] However, NYNEX could have worked as a subcontractor to the general contractor, Perini-Powell. To the knowledge of the author, no telecommunications company has called into question the CA/T communications system project.

[99] According to a press release from Perini-Powell, "The Perini/Powell joint venture will design and install a fully-integrated traffic control system that will maintain the surveillance of traffic along Boston's Central Artery and Third Harbor Tunnel by means of a sophisticated computer system. The system will monitor and control 118 speed limit and lane change signs and 39 variable message signs providing current traffic information. In addition, the division will also furnish and install an emergency assistance radio system, an emergency telephone system, a closed circuit television system, a heat detection and fire alarm system, and the control system for high-capacity ventilation fans. Work on the project will begin immediately with completion scheduled for June 1998" ("Perini Division Awarded Three New Construction Contracts"). The total contract award is for $52 million.

[100] Cost includes controller equipment, single-mode fiber, and multimode fiber. The multimode fiber is used to connect system components such as video cameras to the main backbone.

rely upon industry standards which will in turn probably be adopted by other state agencies on a voluntary basis.

Project planners are confident that the system can easily be upgraded using off-the-shelf components; the equipment vendor will be responsible for ensuring that its products provide sufficient interoperability and extensibility. CA/T management expressed confidence that the equipment selected by Perini-Powell is high quality and meets all of the project specifications. Life-cycle cost data suggests that Perini-Powell will succeed in making a profit from the project.

The project also includes the deployment of technology to support wireless communications. Notably, the deployment extends the wireless communications systems of the Boston Fire Department, Boston EMS, the State Police, MBTA Police, and MTA to serve sub-surface portions of the CA/T infrastructure.[101] As noted by project planners in the 1990 concept report, ensuring interoperability and compatibility of networks is an important goal of the deployment. Regional planning was performed by the state to ensure that wireless transponder systems, which can be used to support electronic toll collection or monitoring of traffic probe vehicles, would be interoperable.[102] The standard was established though a memorandum of understanding among various Massachusetts transportation agencies. One project planner commented, however, that it is a "miracle" an agreement was reached because of the dynamics of Massachusetts politics. At this time, there is no single entity responsible for information technology planning in the Commonwealth. Agency concerns about autonomy and turf make multi-agency coordination difficult.[103]

The 1990 concept report specifically recommends that the state adopt a policy regarding leasing reserve capacity. Although the overall report was endorsed by the project managers involved in the deployment, no formal policy was adopted. The standard engineering practice is to

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[101] Regional cellular carriers are also being provided access to cell sites. However, the state will not be responsible for installation, operations, or maintenance of private infrastructure.

[102] Probe vehicles are used to monitor traffic flow along arterials. For example, if the velocity of a probe vehicle become very slow, managers in a central traffic control center would become aware that there may be a congestion problem.

[103] One project planner suggested that developing a "think tank" to plan state-wide telecommunications deployment strategies would be useful.

build as much as 50 percent extra capacity for potential future needs, but no plan exists to systematically lease reserve telecommunications capacity for the CA/T system. One project planner suggested that if a state agency could demonstrate a compelling need to access the CA/T telecommunications infrastructure, the MHD would probably provide access. However, fiscal constraints associated with the project limit the extent to which new costs may be incurred by MHD.

A policy was established to reserve conduit capacity for future needs. The Boston Transportation Department has expressed an interest in using conduit capacity in the third harbor tunnel.[104] However, according to state planners, much of the right-of-way for the rest of the CA/T system may not be marketable because it is 70 to 100 feet below the earth's surface and therefore not easily interconnected to surface-level telecommunications customers.[105]

The Commonwealth is actively working to exchange right-of-way access for fiber along the state's highways.[106] For example, the MTA obtained fiber under a contract with four telecommunications companies that paid an estimated $25 million to deploy fiber along the Massachusetts Turnpike (I-90) and will pay about $50 million over 30 years to access the Turnpike's right-of-way.[107] The MTA paid an estimated $5.5 million and received twelve fibers as part of the deal.[108] The MTA agreed to allow the Commonwealth of Massachusetts to use four of

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[104] The conduit in the tunnel may be of particular interest to various organizations because the fiber is protected; fiber deployed in a shipping channel outside of buried infrastructure may be susceptible to damage due to dredging or other harbor activity.

[105] This suggests that the state may not have been well positioned to leverage right-of-way access to obtain communications capacity for the CA/T project.

[106] The MHD's policy is described in "Wiring Massachusetts" by Weld, et al. The position paper specifically states "In exchange for the rights to the highway Right-of-Way and other property, the MHD will receive system capacity. For optical fiber conduit systems, the MHD will receive exclusive use of the 'Commonwealth Component,' defined as, three 1.5 inch diameter conduits, lateral branching, manholes and handholes where ever a participant requires the same, and lateral branching for the MHD's Intelligent Transportation System equipment. For tower facilities, the MHD will receive exclusive use of reserved tower space including all tower connections and structural support and electrical power supply required for the Commonwealth's equipment. The Commonwealth Component shall be deemed to be a shared cost among all participants in the Telecommunications Facility and shall be constructed and maintained by the Lead Company. Thereafter, and upon completion of construction, title to all improvements on the premises shall vest in the Commonwealth, excluding any participant's Personal Property. As this initiative currently anticipates optical fiber cable and wireless tower facilities, other Telecommunication Facilities will require separate negotiation."

[107] The Massachusetts Turnpike Authority has an explicit policy not to lease reserve telecommunications capacity but does lease conduit capacity and exchange conduit capacity for communications capacity.

[108] Palmer (no page number).

the twelve fiber-optic lines that it controls. The state plans to continue to pursue similar arrangements for the purpose of developing its telecommunications infrastructure. The MTA's fiber network will eventually be integrated into the CA/T communications system. Some of the fibers along the turnpike will be used for education applications.

Several lessons can be learned from the CA/T deployment. First, there may be technical justifications for not sharing telecommunications infrastructure. In this case, the limited physical extent of the system (7.5 miles) and its sub-surface location (70-100 feet) may be a major impediment to infrastructure sharing. Second, state and federal policies to promote the development of telecommunications systems for a wide range of applications may have been lacking. As one project planner noted, people just did not foresee the possible uses of the fiber network beyond the immediate needs of the MHD. Third, some multi-agency coordination is possible even without formal mechanisms for promoting coordination. In this case, agency coordination was fostered by the development of a memorandum of understanding that determined basic standards to ensure interoperability and compatibility of wireless transponders.

3.4 Texas Case Study: San Antonio ATMS

The San Antonio District of the Texas Department of Transportation (TXDOT) is developing an Advanced Traffic Management System (ATMS) that will provide transportation and law enforcement officials with real-time information about accidents and incidents on the San Antonio highway system.[109] The traffic management system includes variable message signs, CCTV cameras, vehicle detectors, and signaling for intersections and lane control. The deployment will eventually service 191 miles of highway, the initial 26 miles of which is complete.[110] The San Antonio project includes the development of a fiber-based communications network to support the ATMS. The backbone will utilize the SONET standard and will run at OC-3 (155 Mbps) speeds. The network is fully redundant and uses single-mode fiber.

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[109] Note that the Texas Department of Transportation has 25 districts.

[110] An additional 18 miles is being deployed at this time. Agency staff hope to issue an RFP for another 10 mile stretch within the next 12 months.

Five aerospace companies bid to construct the initial 26 miles of the ATMS. The Request For Proposal (RFP) identified the complete design and scale of the system and bundled construction of the communications system with other ITS components. No consultants were involved in the design process. The $32 million contract was awarded to the low bidder, AlliedSignal Technical Services, which will install the ATMS, including the operations control center and the communications system. The 26-mile stretch includes 50 variable message signs, 59 CCTV cameras, 359 lane change signals, 800 loop detectors, and 15 signalized intersections. RFPs will be issued for remaining portions of the ATMS, which will eventually service 191 miles of highway with approximately 500 CCTV cameras and 300 variable message signs. The overall cost for the ITS deployment is estimated at $151 million.

The decision to develop an owned system was made in-house by staff at the TXDOT San Antonio District office. The District staff is centrally responsible for setting deployment priorities and designing systems, and does not need permission from TXDOT in Austin to deploy new infrastructure. However, approval from the Federal Highway Administration (FHWA) was necessary because 80 percent of the funding for the deployment is being provided by the Federal Government. Outside consultants did not contribute to the decision to own rather than lease the communications system.

A formal study of lease/own tradeoffs was not completed because telecommunications capacity was clearly not available and the cost disadvantages of leasing were "obvious" according to a project manager. Southwestern Bell, the regional telephone company, did not have the necessary infrastructure in place to support broadband communication, which typically requires at least DS3 (45 Mbps) capacity.[111] Moreover, even if DS3 lines were in place, the leasing option could have been rejected on the basis of cost alone, because broadband capacity is typically very expensive to lease. Reliability was not a decision factor; leased services would probably have been sufficiently reliable to support transportation applications according to TXDOT staff. Although it was noted that not all TXDOT Districts are equally capable of handling operations and

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[111] DS0 (64 Kbps) and DS1 (1.5 Mbps) are not fast enough to support full-motion video.

maintenance for complex ATMS, staff with the San Antonio District expressed confidence that they have the personnel needed to ensure system reliability.

The San Antonio District is considering leveraging its right-of-way for future deployments.[112] The utilities use the right-of-way now, but preferred access could be offered. If future cost advantages may be obtained by leasing capacity from a private carrier, the District will consider this option for future deployments as well.[113]

Thus far, the District is satisfied with the deployment, and no technical problems have arisen. The system will become part of a regional traffic management system that will be operated out of the San Antonio control center. Eventually the system could extend across a 50,000 square mile region.[114] For example, TXDOT - San Antonio plans to interconnect TXDOT offices in San Antonio and Laredo by deploying a 155 mile stretch of fiber along I-35. Thus, the regional deployment strategy is involving multiple Districts as well as city agencies such as the San Antonio police and fire departments.

Many public- and private sector organizations have tried to gain access to the fiber capacity being installed by the TXDOT San Antonio District. For example, the University of Texas at San Antonio wanted to interconnect two campuses using capacity provided by TXDOT in exchange for providing the District free Internet access. However, the deal was rejected because staff determined that the arrangement could result in the classification of TXDOT as a public utility, which was deemed undesirable. Thus, as seen before in the MHTD case study, important legal considerations may limit the institutional arrangements selected by state agencies deploying telecommunications networks.

Another important consideration limiting the incentive to share capacity is that the system is designed with sufficient communications capacity to meet future ITS needs, but extra capacity is

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[112] However, the Telecommunications Act of 1996 contains provisions that may make "preferred access" arrangements more difficult to establish.

[113] Note that in Houston a CCTV system that includes a fiber communications backbone is being leased from a private-sector service provider.

[114] The region is comparable to the size of Pennsylvania, which covers 45,000 square miles.

unavailable. Thus, there may be a technical disincentive to sharing, at least as the present system is designed.

3.5 California Case Study: City of San Jose

The City of San Jose is working on a Traffic Signal Management Project (TSMP) and a Motorist Information Systems Project (MISP) as part of its ongoing efforts to deploy ITS. The deployment involves applications such as changeable message signs, video surveillance, and traffic-light control. The system includes CCTV cameras, message signs, and intersections with communications capabilities. By June of 1996, 550 of San Jose's 650 intersections will be connected to the control system.

In 1990, an ITS deployment options report was provided to the City Council by DKS Associates and the City of San Jose Department of Streets and Traffic (SJDST).[115] Initial deployment of the TSMP began in 1991, and completion is anticipated in June 1996. Total funding for the ITS deployment is $26.8 million, of which $7.9 million is from the city and $18.9 million is from grants. The cost for the fiber component of the system is not available because of cost accounting difficulties involving the conduit, which is shared for twisted pair and fiber infrastructure. Construction of the communications system as well as operations and maintenance is handled by SJDST.

Twisted pair is being used for interconnecting traffic intersections, which are equipped with 1200 baud modems. The communications at each intersection supports alarm monitoring and remote traffic signal adjustment.[116] Loop detectors measure traffic flow, providing data that is used to create a schematic representation of the traffic flow at the traffic control center. About half of the twisted pair lines are leased and the remaining are owned by the city.

Fiber is being installed to support full motion video with the intention of potentially developing segments of the system into a communications backbone.[117] The system is compatible

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[115] At the time, the Department was named the San Jose Department of Streets and Parks (SJDSP).

[116] An alarm indicates when a signaling device has failed.

[117] However, the TSMP is primarily comprised of twisted pair infrastructure.

with the Fiber Distributed Data Interface (FDDI) standard and may be upgraded to the SONET standard if a backbone is installed. The system is configured using a hub topology, with one fiber dedicated to interconnecting each CCTV camera to the central traffic control center.[118] There are no multiplexers in the system; single-mode fiber was installed to support future upgrades. Some fiber is being used to interconnect City Hall and several city departments which have data networking requirements. The city wholly owns and operates the fiber system.

System planning considered the total budget of the project with the objective of maximizing both the total amount of city owned infrastructure and the overall capabilities of the ITS system. Owned infrastructure was considered superior because SJDST wanted to avoid the uncertainty of leasing costs and felt that the Department would be much more likely to prioritize maintenance than a private sector service provider. The City Council was made aware that higher-end ITS deployment options would require a larger funding commitment for operations and maintenance. The City Council agreed to provide necessary funding to support staffing requirements, but grant money obviated the need to request full funding. Note that even when outside funding is identified by city staff, grant acceptance approval must be obtained by the City Council which then empowers the City Manager to execute the terms of the grant.

The Information Systems Department is centrally responsible for developing city-wide telecommunications standards. For example, the department has promoted the development of a city-wide government electronic mail system. SJDST staff expressed the belief that having a department responsible for coordinating city-wide networking strategies is helpful because it promotes network interoperability.

At this time the city does not lease capacity to public- or private entities because it is reserved for future ITS requirements. However, the City of San Jose Telecommunications Working Group, which is comprised of representatives from the City Manager's office and various departments, is developing a leasing policy; no formal plans have been adopted.[119] Private

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[118] At this time, 18 CCTV cameras are operational.

[119] This initiative is ongoing and was mentioned in both interviews with SJDST staff.

telecommunications service providers have not expressed any concerns with the city's deployment of telecommunications infrastructure to support the TSMP.

A new water distribution system being built in San Jose to satisfy Environmental Protection Agency regulations will require much of the city's right-of-way to be opened for construction. The city may use this opportunity, and its ability to leverage right-of-way, to develop a fiber-optic backbone to support ITS.[120] At this time there is considerable private sector interest in using this opportunity to access the right-of-way and deploy fiber.

Some problems with the Department's installation work for the TSMP have arisen due to the staff's lack of familiarity with large-scale systems implementation.[121] However, staff expressed confidence that as their familiarity with the technology grows, system operations and maintenance should function smoothly. No major problems are anticipated.

Several lessons can be learned from the experience of the SJDST. First, providing less autonomy to individual governmental organizations may promote coordination of network deployment. The Department is required to obtain approval for funded projects from the City Council which may explain why the network presently serves multiple users, interconnecting City Hall and several city departments. (Arguably, a state agency is vested with greater autonomy and therefore may have fewer incentives to coordinate telecommunications deployment with other state agencies than a city department with other city departments.) Second, the existence of a separate department responsible for developing city-wide telecommunications standards apparently promoted network interoperability. In this case, the Information Systems Department coordinates information technology policy by taking into consideration multi-department networking requirements. The case suggests that the experiences of localities and state agencies may be significantly different due to the level of city department autonomy as compared with the level of state agency autonomy.

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[120] The Telecommunications Act of 1996 includes a provision limiting the ability of localities to charge for access to right-of-way. However, according to SJDST staff, this provision will not affect the viability of joint development opportunities.

[121] Problems were noted during both interviews. However, staff expressed confidence that the Department is successfully dealing with the problems.

3.6 California Case Study: Bay Area Rapid Transit

Bay Area Rapid Transit (BART) operates a major rapid transit system in the San Francisco Bay region and is presently deploying ITS through a joint development project with MFS Network Technologies (MFSNT). The deployment consists of two separate but related projects. First, MFSNT will build and maintain a conduit system in the BART-owned right-of-way, which will provide revenue to both BART and MFSNT. Second, MFSNT will deploy a new fiber-optic and wireless telecommunications system, called the Bart Telesystem, that will be wholly owned and operated by BART. Conduit will be installed along 71 to 86 miles of track with space reserved for a sheath of 48 fiber strands dedicated to transportation applications. The total cost of the fiber system including controllers is about $7 million.

Kingston Cole Associates provided consulting advice for the joint conduit development and suggested that the conduit could pay for itself and provide enough revenue to pay for the BART Telesystem. The Telesystem was designed in-house by BART staff. MFSNT and BART finalized the agreement in December 1994.

The ITS system will eventually include high-resolution video surveillance systems, video monitors to provide traveler information, train control and monitoring, and destination sign and announcement control. Many of these systems are already operational; however, applications such as video surveillance will not be available until broadband infrastructure is in place. The Telesystem will support all of BART's needs, including communications for police and maintenance workers.

In the spring of 1993, BART issued a Request For Proposal (RFP) that provided several options for bidders. The first option was to bid on installing conduit in a joint development project with BART that would involve sharing profits from conduit tenants. The second option involved bidding on both the conduit joint development and the Telesystem as a package deal. The third option provided the opportunity to bid on obtaining right-of-way for cellular sites that would allow a cellular carrier to provide its customers service within the transit system. MFSNT was selected in August 1994 as the top candidate because of its willingness to bid on both the conduit joint development and the Telesystem. The only other bidder willing to handle multiple portions of the project was Info Systems Incorporated, a California-based company. However, the company was not considered as a serious contender because the size of the job was deemed too large for the relatively small company.

The joint development for the conduit system provides for the installation and maintenance of a four-inch conduit with an inner duct reserved for the exclusive use of BART. MFSNT will market the remaining capacity to telecommunications service providers and will split the revenue with BART, which will receive a 91% share.[122] MFSNT will invest about $3 million to build the conduit system.

MFSNT will build the Telesystem and provide training to BART employees, who will then be responsible for operating and maintaining the system. The Telesystem includes both wireless and fiber technology, which provides system redundancy along with offering versatility. Wireless will primarily be used for police and maintenance communications, and the fiber will support applications such as video surveillance. Fiber was selected because it provides security and broadband capacity and is not susceptible to electromagnetic interference.[123] The total cost of the BART Telesystem, including both fiber and wireless components, is about $44.6 million, which is being financed by Pitney-Bowes Credit Corporation (PBCC).

All the fiber being installed is single-mode and will initially run at OC-3 speeds (155 Mbps). The California Department of Transportation (Caltrans) will receive control of four fibers for its Traffic Operations System (TOS) because some of the conduit will utilize right-of-way that is jointly controlled by Caltrans and BART. The decision to procure a fiber network was made primarily within BART, although Caltrans was also involved because of the shared right-of-way.

It was felt that the Telesystem should be wholly owned and operated by BART in part because relying upon a third party in an emergency was considered highly undesirable. A strong

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[122] MFSNT will own the conduit during the license agreement. After 15 years, if MFSNT decides not to continue the arrangement, the conduit will be sold to BART for $1. MFSNT is responsible for operations and maintenance of the conduit unless ownership of the conduit transfers to BART.

[123] Presently a T1 carrier is being used to support some of BART's telecommunications needs. However, T1 capacity is insufficient to support broadband applications.

belief was expressed that leasing capacity would undermine the quality of the transit system. There was a strong interest in maintaining full control of the system and it was described as the "philosophy" of BART to do so. It was also noted that the transit system has unique needs that are not comparable to fiber deployments that support highway-oriented ITS applications because much of the system is subsurface and includes unique operations such as vehicle control. Leasing capacity from a private company to provide system redundancy was considered, but the provider would have required access to the right-of-way controlled by BART. This seemed inappropriate because BART would then effectively be paying a private company to use its right-of-way rather than leveraging the right-of-way to create a revenue source.[124]

Another consideration in choosing to own rather than lease was that the BART Telesystem is an expensive project. In the absence of a large amount of public funding, the joint development approach was the only feasible option for system development. The arrangement with MFSNT was considered highly compelling because it may create revenue for BART, which, according to the cost analysis performed by Kingston Cole Associates, will not only cover the debt incurred by the project but also provide excess revenue. At this time the exact revenue potential is uncertain because leasing arrangements will be negotiated on an ad hoc basis.

The Telesystem is dedicated for the needs of BART and does not provide any reserve capacity for third parties. The planners considered building and owning a telecommunications system that could offer leased capacity, but this would have required certification of BART as a public utility, which was deemed undesirable. The Telesystem is expected to have enough reserve capacity to satisfy the transit system's communications needs for the next 20 years.

So far there have not been any problems with the work done by MFSNT. It is expected that if there are problems with the project it will not be with the joint development but rather with the Telesystem because integrating the wireless and fiber communications technology will be challenging.

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[124] The BART Telesystem includes a redundant fiber network and the wireless system also provides for additional redundancy.

4.0 FACTORS INFLUENCING NETWORK DEPLOYMENT

The cases presented in chapters two and three raise an important question regarding public management of telecommunications networks: Why are some state-wide networking initiatives, such as the Iowa Communications Network and North Carolina Information Highway, being developed to include a broad range of user services while other deployments, such as those for Intelligent Transportation Systems, are limited in scope to a narrow set of applications? The cases suggest that the factors inhibiting the development of state-wide networks serving multiple agencies are both institutional and political.

Table 4.1 summarizes a few key aspects of the cases that are relevant to the analysis presented in this chapter. The table shows that concerns about political conflict tended to be expressed in the cases involving state-wide, as opposed to metropolitan, network deployment. The table also shows that in half of the deployments intended to serve transportation applications, regulatory concerns influenced government deployment strategies. Other important factors, less amenable to being summarized in tabular format, are discussed in the text.

4.1 Institutional Factors

A wide range of institutional factors are demonstrated by the case studies. The factors include the delegation of authority, regulatory concerns, and agency culture.

The authority delegated to individual government agencies can influence network deployment. Several of the cases presented in chapter three suggest that in many instances legislative or executive approval of network deployment is not required. For example, MHTD and TXDOT each deployed networks without the approval of the legislature in each state. This delegation of authority allowed MHTD and TXDOT to act independently. On one hand, delegation of authority may advantage state agencies by allowing expeditious deployment of new infrastructure. On the other hand, it encourages independent action that does not necessarily consider whether multi-agency initiatives would promote technical efficiency.

TABLE 4.1 - SUMMARY OF CASES

Case	*Primary applications*	*Scope of deployment*	*Ownership model*	*Political conflict*	*Regulatory concerns*
ICN	• Education • Social services • Criminal justice	• State-wide	• Government owned (phase I&II) • Mixed (phase III)	• Conflict with telco lobby • Conflict with legislature	• None identified
NCIH	• Education • Social services • Criminal justice	• State-wide	• Private	• Conflict with legislature over long-term funding	• None identified
MHTD	• Transportation	• State-wide	• Private (shared resources arrangement)	• Planners sought to avoid conflict with telcos	• Opposition of Public Services Commission to deployment of network to serve multi-agency needs
ConnDOT	• Transportation	• Limited to segment of one interstate	• Government owned	• None identified	• None identified
MHD	• Transportation	• Metropolitan	• Government owned	• None identified	• None identified
TXDOT	• Transportation	• Metropolitan	• Government owned	• None identified	• Providing services to outside agency would classify TXDOT as a public utility
SJDST	• Transportation	• Metropolitan	• Government owned	• None identified	• None identified
BART	• Transportation	• Metropolitan	• Government owned (shared resources arrangement)	• None identified	• Providing leased services to outside organizations would classify BART as a utility

The SJDST case suggests that the delegation of authority is different at the local level as compared with the state level. Individual city departments may have less autonomy compared with state agencies because city councils may be capable of exercising tighter control over the deployment of new infrastructure compared with state legislators or governors.

Interestingly, SJDST planners noted that having a separate department responsible for information technology planning promoted effective network deployment and utilization. Similarly, the ICN was established as an agency within the State of Iowa which may have provided it with a broader view of government information technology planning than if it had been established merely as a subsidiary to the Iowa Department of Education. The delegation of authority in these two cases may have promoted the consideration of multi-agency networking requirements.

Another institutional factor involving the delegation of authority is financing. Financing options available to state agencies may not favor sharing, at least for transportation agencies. As demonstrated by the MHTD and BART case studies (see Table 4.1), transportation agencies have successfully negotiated with private companies to exchange right-of-way for communications capacity; the BART deal may even provide a revenue stream to the public sector. However, there appears to be little incentive to share right-of-way leveraging capabilities with other state agencies that lack control of this important public resource.

Beyond the issue of the delegation of authority, the cases also suggest that there may be regulatory impediments limiting the scope of network deployment (see Table 4.1). For example, MHTD briefly considered deploying a network to serve broad needs of state government but ran into opposition from the Missouri Public Services Commission which did not want to allow the state to compete as an unregulated utility against regulated utilities. TXDOT also faced a similar obstacle when it determined that an arrangement to provide the University of Texas with telecommunications capacity could result in the classification of TXDOT as a public utility under state law. BART also determined that offering leased capacity would have required certification as a public utility, which was deemed undesirable.

Agency culture is also an important institutional factor. To some extent, agencies may simply not want to become telecommunications service providers to other state agencies. Several interviewees noted that their agencies have a "philosophical" preference to directly control the infrastructure needed to carry out their mission; sharing telecommunications networks with other public entities may be inconsistent with this preference. Thus, agency culture may tend to favor deployment options that promote agency autonomy. This is certainly true with respect to decisions to develop owned networks rather than lease services from the private sector as demonstrated by the BART case study

4.2 Political Factors

Promoting multi-agency deployment initiatives is a double edged sword. On one hand, multi-agency networks may increase the scope of support for deployment. On the other hand, deployment initiatives that are broad in scope may be easy targets for skeptical interests such as legislators, lobbyists, the media, and the public.

In North Carolina, the governor's office actively sought to promote the NCIH as an initiative to serve broad-based networking requirements. The NCIH is intended to foster applications in education, social services, and criminal justice, as well as generally promote private sector investment in telecommunications. The ICN is also designed to promote the interests of a wide range of constituencies.

Political opposition was an important consideration in the cases involving large scale deployment of telecommunications infrastructure. For example, concerns about political opposition were expressed in the ICN, NCIH, and MHTD cases but not in the BART, ConnDOT, SJDST, MHD, or TXDOT cases (see Table 4.1). The significant prospective ongoing costs of the NCIH have prompted various constituencies to express serious concerns about the sensibility of the project. The large scale of the ICN deployment also caused political conflict as various constituencies questioned the need for a vast state network. MHTD planners sought to avoid political conflict by limiting the scope of deployment.

Scope of deployment is not the only variable influencing the politics of network deployment. For example, ICN planners faced serious political opposition to their program, in part because the state deployed a government owned network. Governor Terry Branstad faced major criticisms for years about the ICN. The public was skeptical; the press was skeptical; and legislators mobilized to kill the project. However, the ICN case seems to suggest that persistence pays off because the ICN is now a functioning state-wide network with a large number of sites on-line.

The cases in chapter three demonstrate that transportation agencies are aware of these political impediments. In the Missouri case study, the MHTD avoided taking on the issue of deploying a network that could serve multiple agencies in part because of potential opposition posed by local exchange carriers. Not only was there concern that a more ambitious approach could cause the project to be killed, but delay was deemed to be detrimental to the project. MHTD planners believed that there was a brief "window of opportunity" available to initiate a shared resources project; if the initiative were delayed due to political conflict, the opportunity to leverage access to right-of-way could have been lost. However, as noted earlier, not all of the cases in chapter three suggest that political factors influence decisions regarding the scope of deployment. In some of the cases, political conflict was notably absent.

The lesson here may be that high level political support is needed to promote the deployment of ubiquitous state networks. In North Carolina, the governor's office prioritized the development of the NCIH. In Iowa, the governor and various members of the legislature were willing to fight for the deployment of a ubiquitous network and appear to have succeeded. Lacking this high level political support, MHTD may have made an appropriate decision to focus on ITS rather than broader telecommunications networking needs. However, the consequence is that an important opportunity to promote the development of a ubiquitous state government network in Missouri by leveraging access to the state right-of-way was lost.

4.3 Alternative Explanations

A wide range of alternative explanations to these institutional and political factors may be provided.

At the most fundamental level, the cases in chapter three suggest that transportation agencies may simply not be considering the potential for fiber-optic network deployments to serve the broader telecommunications requirements of government; this phenomena was exhibited by both the MHD and ConnDOT case studies.

There are also several technical reasons for not sharing infrastructure used for ITS applications with other state agencies. For example, the limited physical extent of the CA/T system (7.5 miles) and its subsurface location (70-100 feet) may be a major deterrent to infrastructure sharing; other state agencies might find alternatives to using MHD's infrastructure to be significantly more desirable. The infrastructure for the BART Telesystem, some of which is deep beneath the earth's surface, may also be difficult to share.

Another important technical consideration is the issue of reserve capacity. Transportation agencies typically deploy networks with enough reserve capacity to meet their own future telecommunications needs and are not installing networks with reserve capacity to meet the needs of other organizations whether they are public or private. Under these circumstances, there is very little incentive to share infrastructure. Obviously, the key to successful multi-agency coordination is to take into consideration the issue of sharing telecommunications capacity when a network is being developed to ensure that sufficient capacity will be built into the system.

Finally, security and privacy considerations may provide important technical reasons not to share telecommunications infrastructure. For example, some transportation agencies handle "mission critical" applications that may not be amenable to network sharing with "outsiders" that will fail to prioritize network security. However, this view may be symptomatic of organizational culture that values autonomy rather than any underlying technical concern. Moreover, infrastructure such as conduit may in some instances be shared without compromising security or privacy. None the less, security and privacy are important issues that information technology planners must consider.

There are other alternative explanations that should be mentioned beyond technical considerations. One argument is that management problems may arise with government deployment initiatives that are broad in scope. Some would argue that the public sector is inherently incapable of managing telecommunications networks, a problem that is exacerbated by broadening the scope of deployment. This thesis does not address the question of whether state and local governments should promote the development of owned infrastructure as opposed to leased infrastructure.[125] However, because public agencies have a strong incentive to pursue cost-effective deployment strategies, and are in many instances deploying government owned networks, it seems logical to conclude that in some circumstances government ownership is appropriate.

4.4 Conclusions

Telecommunications network deployment initiatives are often limited in scope in accordance with the political clout of the enabling organization. State legislatures, governors, city councils, and mayors tend to have much greater ability to promote multi-agency or multi-department networking initiatives than individual state or local agencies. Transportation agencies tend to optimize technology deployment and management strategies to conform with agency authority and traditional self-perceived public responsibilities.

Mechanisms for promoting multi-agency networks are needed. In circumstances where technical efficiency may be promoted, state and local governments should consider developing ubiquitous networks that can serve the total telecommunications needs of government regardless of whether leased or owned strategies are adopted; network interoperability and cost-effectiveness should not be compromised due to institutional obstacles or political conflict. The public interest can best be served by ensuring that government agencies may adopt deployment strategies that are

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[125] See Melcher and Roos (see references) for a discussion about lease versus own considerations exemplified by the case studies in chapter three.

not unduly constrained by institutional and political conflict. In chapter five, several mechanisms for dealing with some of the impediments to multi-agency coordination are discussed.

5.0 POLICY RECOMMENDATIONS

New institutional arrangements that promote multi-agency deployment and utilization of government telecommunications networks may help alleviate some of the barriers to multi-agency networking initiatives, and accordingly promote technical efficiency. Two general recommendations for dealing with institutional and political impediments to multi-agency initiatives are examined in this chapter. The discussion considers the potential impact of state information technology planning entities and the role of the U.S. Department of Transportation.

5.1 Information Technology Planning Entities

States use a wide variety of institutional arrangements to facilitate multi-agency information technology planning including Information Resource Management Commissions (IRMCs), Chief Information Officers (CIOs), and legislative oversight committees.[126] Such entities, to varying degree, are given explicit legal authority over aspects of state information technology planning. The author speculates that multi-agency deployment and utilization of telecommunications networks could be promoted by providing multi-agency information technology planning entities with greater authority over the deployment of telecommunications networks, especially those used to support ITS applications. Depending upon the state, increased authority could be provided by means of legislation or executive order.

Ad hoc, voluntary mechanisms for promoting multi-agency information technology planning can only go so far in promoting effective policies. As noted in the MHD case study, one state planner believed that it was a "miracle" that a memorandum of understanding between various state transportation agencies was adopted on wireless transponder standards.[127]

Several cases suggest that individual states benefit from information technology organizations with broad prerogatives. For example, the ICN was established as a separate

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[126] Note that an IRMC in North Carolina is responsible for oversight of the NCIH and other state information technology initiatives.

[127] Interestingly, the planner also noted that the state might benefit from the development of a "think tank" capable of providing a vision for state-wide information technology planning in Massachusetts; a think tank is one model for an information technology planning entity.

agency, demonstrating that the purpose of the network would be to serve multi-agency telecommunications requirements; if alternative institutional arrangements had been selected, the scope of the ICN might never have expanded beyond the original plans to support distance learning applications. In the San Jose case study, staff with the SJDST noted that the existence of a separate department responsible for information technology planning was useful, providing overall guidance for information technology planning efforts.

In none of the cases presented in chapter three did transportation planners indicate that an external state information technology planning entity played a role in deployment.[128] This suggests that, at best, relevant information technology planning entities provided cursory approval for the deployment of telecommunications networks for ITS. At worst, information technology planning entities are not even aware of these deployments. State information technology planning entities should receive detailed planning reports on information technology deployment initiatives from each state agency, including transportation agencies deploying ITS.

An organization with a legal mandate to coordinate multi-agency information technology planning, including for ITS, might be able to overcome some of the institutional impediments to multi-agency initiatives discussed in chapter four. First, such an organization would have a multi-agency agenda and therefore could potentially transcend concerns about autonomy; the cases suggest that having such an organization might be perceived as desirable by some transportation agencies. Second, the organization would have explicit legal responsibilities, overcoming problems associated with the delegation of authority.

Information technology planning entities may also be able to respond to some of the political factors discussed in chapter four by raising the level of awareness about information technology planning. As noted by the National Governors' Association, "Clear statements of telecommunications needs enable vendors to prepare more responsive bids for services."[129]

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[128] Note that although SJDST worked with another city department, a state level planning organization was not involved.

[129] National Governors' Association, p. 17.

However, as demonstrated by the ICN and NCIH case studies, high profile initiatives may also be more likely to be scrutinized, especially if the bids of powerful interests are rejected.

At a technical level, information technology planning entities may also be able to recognize situations where multi-agency information technology planning is not needed. For example, in situations where the location of a planned infrastructure deployment is not amenable to resource sharing -- in other words, there are technical reasons not to share infrastructure -- such an entity could simply allow deployment to proceed without question.

As noted in section 5.3, the precise role of information technology planning entities in the deployment of ITS and other state networking initiatives should be the subject of future research.

5.2 Role of the U.S. Department of Transportation

Another mechanism for dealing with the institutional and political factors discussed in chapter four is for the U.S. Department of Transportation to take a more active role in ensuring that ITS planning activities provide for multi-agency deployment and utilization of telecommunications networks. USDOT could create incentives for ITS planners to fully apprise state CIOs and IRMCs of network deployment initiatives. (Discussions would need to occur early in the planning process to ensure that reserve capacity for non-transportation applications is made available.) Projects that provide for multi-agency coordination could be prioritized for USDOT financing. As noted in several of the case studies, USDOT is a major source of financial support for ITS deployments.

Enhancing the role of USDOT would serve to promote two main objectives. First, by involving transportation agencies in multi-agency initiatives, the proposal could promote the use of networks not originally developed for transportation applications to be used to support ITS. For example, promoting multi-agency coordination in Iowa might prod IDOT to consider ways to use the ICN for ITS applications. Second, multi-agency resource sharing and procurement policies could lower the costs of deploying ITS for both states and the Federal Government.

The ability of this proposal to respond to political impediments to multi-agency deployment and utilization of telecommunications networks is less clear. On one hand, it could encourage state and local transportation agencies to take on political battles that might lead to the deployment of more technically efficient telecommunications networks. On the other hand, the policy could be opposed by telco interests at the national level because of its potential to encourage further development of state owned infrastructure. None the less, USDOT should promote multi-agency coordination because of its potential to realize cost savings and the scarcity of public sector financial resources.

Obviously, promoting multi-agency deployment and utilization of telecommunications networks using this proposed mechanism requires flexibility. If USDOT were to adopt strict regulations, not formulated as incentives, it could discourage state and local initiatives to deploy ITS.

State and local information technology planners should be directly asked whether USDOT could constructively promote coordination; proposals for enhancing the role of USDOT should be solicited. New statutory authority and/or regulations may be required.

5.3 Future Research

Future research in this area should focus upon a broader and more thorough survey of state information technology planning, asking how information technology planning entities may be improved, and whether USDOT should take a more active role in ensuring that state and local ITS planning activities consider multi-agency networking requirements. Furthermore, the experiences of non-transportation oriented agencies should be examined to more fully ascertain the extent of multi-agency coordination.

Future research should also include extensive interviewing of state officials responsible for multi-agency information technology planning. The cases presented in this thesis focus on the perspectives of individual state agencies that are physically deploying telecommunications infrastructure. Another round of interviews could consider the perspectives of information technology planning entities such as IRMCs and CIOs.

Legal research is also needed. The precise factors determining when a state agency will be classified as a public utility should be identified, and appropriate responses to this impediment should be developed. (Note that neither of the previously described policy recommendations overcomes this impediment.) The legal authority that would be delegated to improve the effectiveness of information technology planning entities is also of interest as well as statutory and regulatory changes that could be adopted to develop the role of USDOT in promoting multi-agency networking initiatives.

5.4 Conclusions

The case study analysis presented in this thesis shows that improved institutional arrangements are needed to alleviate some of the institutional and political impediments to ubiquitous network deployment. The broad potential uses for telecommunications networks should be considered by state and local information technology planners. Visionary leaders at the highest levels of government, capable of promoting technically efficient network deployment, will be essential to the development of cost-effective, interoperable government networks.

APPENDIX A - NETWORK TECHNOLOGY AND DEPLOYMENT

Introduction

Fiber-optic networks are an integral part of supporting the backbone communications needs of state and local government networks. This appendix explores the basic technology and components of fiber networks, as well as engineering design issues, and broader managerial considerations.[130]

Basic Technology and Components of Fiber Networks

At the most basic level, a fiber network consists of a light source, optical fiber that serves as a wave guide, and a receiver that detects the transmitted signal. Typical light sources include the laser injection diode and the light emitting diode. The fiber itself can support single or multimode light transmission depending upon the physical characteristics of the wave guide. Typical light detectors include the PIN diode and the avalanche photo diode (APD). This section describes some of these components in more detail.

A generic fiber-optic system is depicted in Figure A.1. Multiple incoming voice, video, and data signals are converged onto a single channel for transmission over the optical fiber. The multiplexer, which is a hardware device, supports line-sharing among different input devices. The out-coming signal is then processed by a coder that drives the light source which in turn emits an optical signal into the fiber. Depending upon the length of the fiber, an optical repeater or amplifier may be required. A light detector then converts the optical signal into an electrical signal which is processed by the decoder and finally de-multiplexed at the destination.

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[130] This discussion is based upon material from Nellist, Pooch, and Keiser (see references).

FIGURE A.1 - FIBER-OPTIC NETWORK[131]

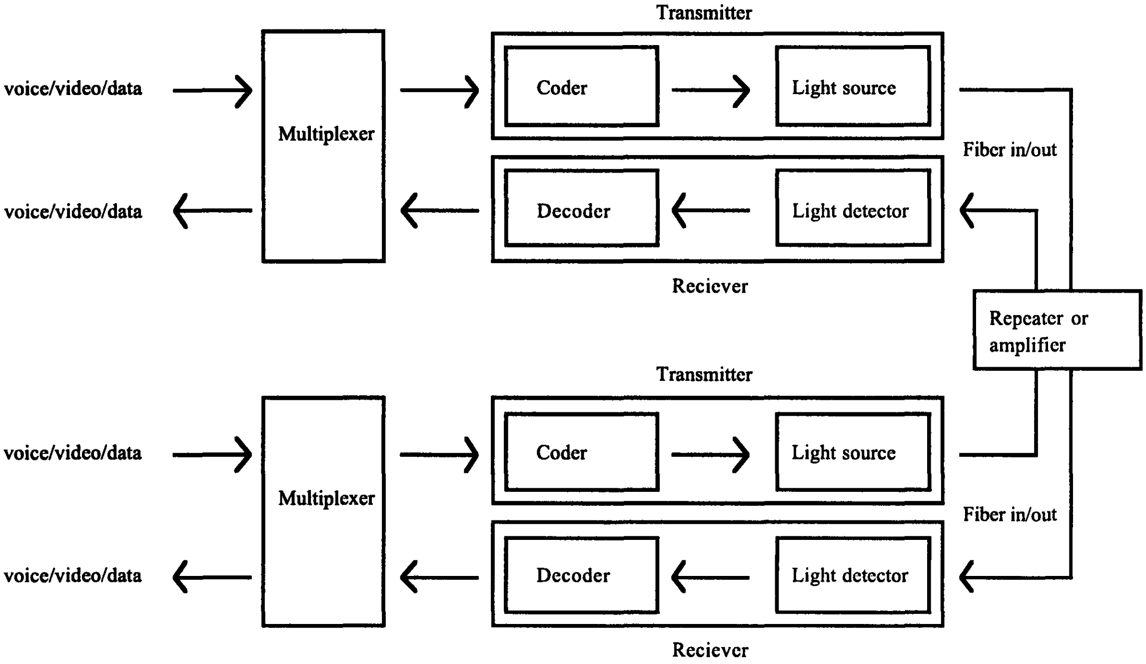

Figure A.1 shows a schematic representation of a fiber-optic network. Voice, video, and data signals are multiplexed onto a fiber backbone which consists of transmitters, receivers, and repeaters/amplifiers.

Fiber

An optical fiber is a wave guide that transmits light by means of total internal reflection. The fiber itself is composed of a transparent inner core and an exterior cladding which has a lower index of refraction.[132] Light can propagate only at certain modes down the fiber depending upon its construction. There are three basic types of fiber: multimode step index, multimode graded index, and single-mode (see Figure A.2). Fiber can be made of plastic but is usually made of silica because of its higher quality.

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[131] Pooch, p. 162.

[132] The index of refraction is defined as the velocity of light ($3x10^8$ meters / second) divided by the velocity of light in the propagation medium which is a function of wavelength.

FIGURE A.2 - FIBER TYPES[133]

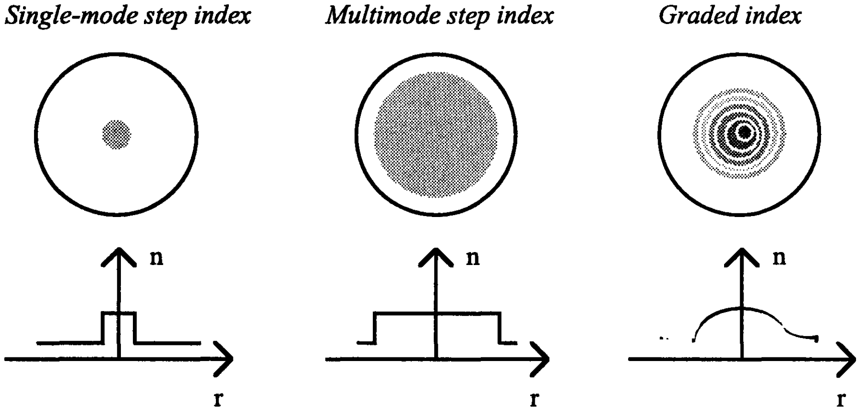

Figure A.2 shows three types of fiber-optic cable in cross section. Note that n denotes the index of refraction and r the radius. The single-mode fiber consists of an inner core (about 8 micro meters in diameter) and outer cladding (about 125 micro meters in diameter). For the multimode fiber the cladding is of comparable diameter but the inner core diameter is about 50 micro meters.

Attenuation and dispersion are two of the key characteristics of optical fibers that are important considerations for communications network design.[134]

Attenuation, which is measured in decibels (dB) per kilometer, describes the phenomena of signal amplitude degradation over distance. Eventually a repeater or amplifier must be used to regenerate the signal and compensate for losses. The attenuation is a function of wavelength and the individual properties of the fiber. There are three important transmission windows in the attenuation versus wavelength profile which occur at about 850, 1300, and 1550 nm wavelengths.

Dispersion, which is measured in nanoseconds per kilometer, is a phenomena associated with signal spreading or broadening over time. There are several types of dispersion. Modal dispersion is caused in step index multimode fiber because the light rays travel along slightly

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[133] Keiser, p. 339.

[134] The numerical aperture of the fiber, which corresponds to the range of angles over which an optical signal will successfully enter a fiber and be transmitted, is another important characteristic.

different paths, corresponding to the various modes of the fiber, which means some light travels a longer distance in the fiber and takes longer to reach the detector. Dispersion can be reduced using graded index fiber which instead of jumping from one index of refraction to another changes continuously from the edge of the core outward. By making the core even smaller, only one mode will propagate, alleviating the modal dispersion problem altogether. This is an important advantage of single-mode fiber.

Another important dispersion phenomena is known as chromatic dispersion. Chromatic dispersion is caused by the physical characteristics of the fiber and the light source. Pulse spreading occurs because a typical light source is not monochromatic but rather emits over a range of frequencies. In an optical transmission medium, the speed of light is a function of wavelength. The optical line width of the light source will contribute to the broadening of the initial signal.

Dispersion reduces that rate at which information can be accurately transmitted over fiber. As incoming pulses spread into each other the transmitted information is increasingly difficult to discern leading to bit transmission errors. As the length of an optical fiber increases, dispersion problems become more significant. Single-mode fiber has the lowest dispersion and is appropriate for long haul networks which have repeater spacing on the order of 30 km. Multimode fiber works well in systems extending over several kilometers. Graded index fiber is an appropriate alternative between the characteristic extremes of these two technologies. Table A.1 summarizes some of the advantages and disadvantages of various types of fiber.

TABLE A.1 - COMPARISON OF FIBER TECHNOLOGY

Type	*Advantages*	*Disadvantages*
Multimode step index	• Relative ease of interconnection[135]	• Dispersion
Multimode graded index	• Relative ease of interconnection • Less modal dispersion	• Dispersion
Single-mode	• No modal dispersion	• Harder to interconnect fibers

Advantages of Fiber

Compared with alternative transmission mediums, fiber is often a technically superior option for broadband land-line communications because it is reliable, cost effective, and easy to maintain. Fiber is insensitive to electromagnetic interference and provides network security. Long haul systems of up to 30 kilometers can be attained without signal regeneration. Table A.2 summarizes some of the tradeoffs between various communications mediums.

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[135] Note that as the core radius of the fiber becomes smaller, the acceptance angle of light entering the fiber from the source becomes smaller making it more difficult to interconnect system components.

TABLE A.2 - COMMUNICATIONS SYSTEMS

Communication medium	*Advantages*	*Disadvantages*
Fiber	• Broadband capacity • Secure • Reliable • Not susceptible to electromagnetic interference	• In some cases not cost effective
Wireless	• Supports mobility • Versatile	• Requires spectrum allocation • Lack of standards and interoperability problems • Usually not broadband
Coaxial cable	• Broadband • Infrastructure may already be in place	• Requires intermediate repeaters even over short distances which can reduce system reliability
Twisted pair copper wire	• Infrastructure may already be in place	• Does not support broadband applications

Cable Design

A fiber-optic cable must be designed such that it protects the inner fibers from mechanical stresses induced during installation and use. The cable typically includes an outer sheath, a buffing material, and a strength element.

There are two basic types of construction for a fiber-optic cable. In loose buffer construction the fiber lies freely with a helical wind inside a soft polymer tube. When tension is exerted on the cable, the fiber uncoils from its helical position. When the cable is compressed, the fiber coils. In tight construction the fiber is bound in place within the soft polymer tube.

Cable strength can be enhanced by using a central strength member surrounded by the polymer tubes containing fiber. The strength member reduces the stresses that can be induced upon the fiber due to bending or pulling and is sometimes composed of steel.

The polymer tube is itself enclosed within an outer sheath. Metallic sheaths are sometimes used to reduce the likelihood of cable damage.

Light Sources and Detectors

Solid state devices called diodes are used to emit and detect light in fiber systems. Several kinds of detectors and transmitters can be utilized.

A good light source must have high intensity, exhibit a narrow spectral line width, support fast signal transmission, and demonstrate reliability. A high intensity reduces attenuation problems, and a narrow spectral line width reduces chromatic dispersion.

Emitters include the light emitting diode (LED), the laser diode, and the distributed feedback (DFB) laser. The advantages and disadvantages of these light sources is summarized in Table A.3. The DFB laser is superior to both alternatives because of its narrow spectral line width, but is relatively expensive. For digital transmission systems, the laser diode is the most common emitter.

TABLE A.3 - LIGHT SOURCES

	Advantages	*Disadvantages*
Light emitting diode	• Can be used for both digital and analog transmissions • Successfully used for low capacity and short distance systems	• Low output • Broad output spectrum
Laser diodes	• Higher light output intensity • Narrower output spectrum	• Primarily suited for digital transmission
DFB laser	• Very narrow spectral line width	• Expensive

Detectors must be sensitive enough to detect the transmitted signal, responsive at the emitter wavelength, fast enough to detect high speed pulsing, and insensitive to environmental variables such as temperature. Two commonly used detectors include the PIN diode and the avalanche photo diode (APD). The avalanche photo diode has demonstrated greater sensitivity.

Repeaters and Amplifiers

Repeaters must support high speed, real-time signal regeneration of the source signal. The repeater detects an incoming pulse, processes it, and transmits a new signal with a corrected wave form and enhanced amplitude. A schematic representation of an optical repeater is shown in Figure A.3. Repeaters are designed for specific data rates and codes and therefore must be upgraded if the source transmitter is changed.

FIGURE A.3 - OPTICAL REPEATER[136]

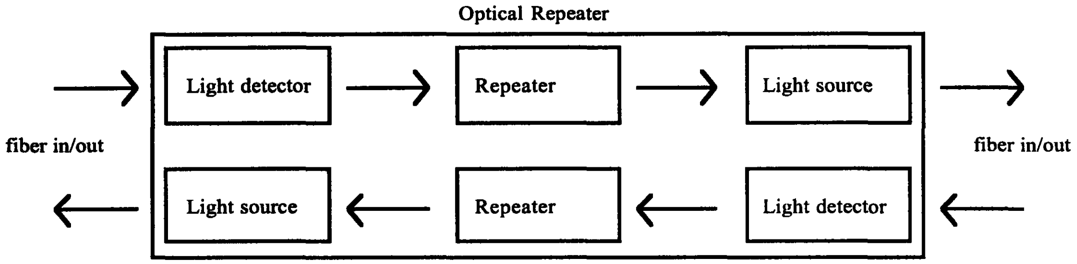

Figure A.3 shows a schematic representation of an optical repeater. A light detector receives an optical signal and converts it to an electrical signal which is then processed by a repeater. The electrical signal is then reconverted back to an optical signal.

Alternatively, optical amplifiers improve the gain of the incoming signal without altering the wave form and are capable of operating at a variety of wavelengths obviating the need for upgrades if the light source is changed. Optical amplifiers do not correct for dispersion effects.

Transmission Standards

There are many proprietary and non-proprietary transmission standards for fiber-optic communications networks. The FDDI and SONET standards are two of the most common non-proprietary standards. Standards promote interoperability of network components that are offered by a variety of system vendors.

FDDI is a standard for optical communications that is based upon token rings and supports 100 Mbps data rates. A token ring controls which of the attached network components may transmit at any given time by passing a "token" or control string of bits between terminals. FDDI uses two tokens which are passed around in a ring in opposite directions.

SONET provides a set of standards for a hierarchy of synchronous optical transmissions. The goal of the SONET standard is to provide for global compatibility of fiber-optic communications systems products. The transmission hierarchy is based upon data transmission rates beginning with OC-1 which corresponds to 51.84 Mbps. Higher data rate levels are derived

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[136] Pooch, p. 162.

from the OC-1 rate. For example, an OC-3 operates at three times the rate of an OC-1. Several transmission levels are shown in Table A.4.

TABLE A.4 - SONET HIERARCHY[137]

Carrier level	*Speed*
OC-1	51.84 Mbps
OC-3	155.52 Mbps
OC-12	622.08 Mbps
OC-48	2.488 Gbps

The SONET standard uses an 8 bit byte that is repeated every 125 microseconds. The result is a 64 kbps channel which corresponds with one voice grade circuit. The SONET transmission format provides for an "envelope" that carries 810 bytes of information with a payload of 756 usable bytes.

Many ITS systems being deployed today rely heavily upon the SONET standard to ensure ease of future upgrades and compatibility of system components.

Network Engineering Design

Building and designing a network requires careful consideration of technology selection, cable placement, and trouble shooting. This section describes some of these considerations. Generally, the goals for any engineering design include reliability, compatibility, extensibility, upgradeability, and cost effectiveness.

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[137] Keiser, p. 364.

Technology Selection

Choosing appropriate technology for deployment requires an examination of the physical characteristics of the system components, such as dispersion and attenuation, as well as future upgrade options.

Technology selection involves selecting between single and multimode fiber as well as a variety of optical electronics. Typical single-mode fiber systems operating at 1300 nm function over a 30 to 50 km range without signal regeneration and can transmit at about 565 Mbps. Using a light source with a narrower spectral line width increases the maximum distance but will also increase costs. Choosing an appropriate system will depend upon the transmission rates needed, the distances involved, and the available resources. Some of the potential characteristics of systems operating at various wavelengths are summarized in Table A.5.

TABLE A.5 - SUMMARY OF FIBER NETWORK CHARACTERISTICS

Wave length	*Fiber Type*	*System Length*	*Approximate data rate*
850 nm	Mulitmode	10 km	45 Mbps
1300 nm	Multimode	20 km	
1300 nm	Single-mode	50 km	565 Mbps
1550 nm	Single-mode w/ single frequency laser	100 km	1.2 or 2.4 Gbps

Selection must take into account attenuation to ensure that the light source will be sufficiently strong, and the receiver will be sufficiently sensitive. Attenuation in a fiber system can be caused by a variety of factors including the physical characteristics of the cable, connector losses, and splices. The power margin, which is defined as the difference in decibels between the light source output and the detector sensitivity, must be sufficiently large to ensure low transmission error rates.

SONET compatible equipment is often selected to ensure extensibility and compatibility. Using equipment that conforms to proprietary standards may make it more difficult to find appropriate equipment and software in the future if a system vendor fails to supply needed equipment or is not cost effective.

Upgrading fiber-optic networks can be accomplished in a number of ways without replacing the fiber itself. Consider an existing 1300 nm system. One option is to use a more advanced communications control technique called time division multiplexing which provides Giga bit data rates. Another option is to operate in the 1550 nm range which reduces attenuation effects. Finally, a technique called wave division multiplexing can be applied which involves using multiple light sources operating at different wave lengths, such as 1300 nm and 1550 nm. Thus, if future bandwidth requirements necessitate upgrades, initial system components, such as the fiber, should be selected to ensure that upgrades are costs effective and easy.

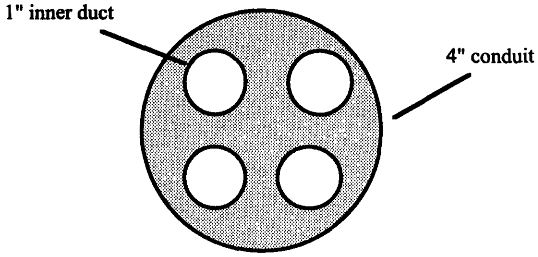
Typically, a complete fiber-optic communications network will use a hybrid of technologies depending upon the requirements of each segment.

Cable Installation

Fiber is available for a wide range of installation conditions including aerial, direct burial, conduit, and undersea placement. Highway authorities developing ITS often build conduit for fiber installation or directly bury cable along right-of-way. Figure A.4 shows pipe conduit in cross section. Conduit location is chosen to avoid traffic disruptions during installation and maintenance and to protect against vandalism or accidental damage. Soil and other environmental conditions determine the feasibility and expense of various cable placement options.

During installation, care needs to be taken to avoid damaging the fiber by excessively pulling or bending the cable. Accordingly, the tension on the cable should be monitored when pulling fiber through conduit which can be accomplished using a rope. (More sophisticated techniques also exist.) Center pulling is sometimes used to reduce the total amount of tension required.

FIGURE A.4 - CONDUIT[138]



Fiber-optic cable is often installed in buried conduit. Typical conduit consists of a 4" outer duct that can be subdivided into multiple inner ducts.

Fiber-optic cable can also be installed by means of direct burial using a special plow. Typically, cable is buried to depths of 3-4 feet and is armored to provide added protection. Marker tape is often buried a few feet above the cable to warn construction workers that there is an underlying cable which could be damaged.

Aerial placement is another option for cable installation. Although cables can be knocked down from aerial locations due to inclement weather, experience shows that aerial fiber can be successfully installed and maintained. Aerial cable is specially designed to handle strains induced by suspension. A steel strand is installed to provide added strength.

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[138] Nellist, p. 144.

Trouble Shooting Fiber Networks

After a fiber network is built, field testing is required to ensure that it is operating properly. An optical time domain reflectometer (OTDR) can be used to detect faults or breaks and determine attenuation losses due to splices and connectors. The device, which measures attenuation as a function of distance, emits optical impulses into the fiber and monitors scattering and reflection phenomena which are caused by the physical characteristics of the fiber and line breaks. Thus, if a fiber network link goes down, field testing can be used to locate the break. OTDRs are available from a wide range of manufacturers.

Broader Considerations

A sensible deployment strategy must consider not only the technical requirements of the communications backbone but also managerial issues. Important considerations include the cost of the system, right-of-way access, and lease/own options. Whereas the technical design considerations of fiber networks are well understood, there is no clear consensus on many of these managerial issues.

Cost

Public agencies sometimes have limited financial resources. Both initial and ongoing costs must be considered when deploying a network. Initial costs include the equipment, software, and installation of the network. Ongoing costs include operations, maintenance, and upgrades. If components of the network are leased, there are also ongoing service costs. Often, public agencies have difficulty meeting ongoing costs because public funding is erratic.

Fiber-optic networks are considered very cost effective for broadband communications requirements over large areas. Many applications, such as video, require broadband, real-time communications to realize their full potential. Kimley-Horn & Associates estimates that the typical ITS freeway communications data load is on the order of 12.5 Mbps per mile.[139] Transportation

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[139] Presentation by Bruce Abernethy at the "Intelligent Transportation Systems Telecommunications Forum" on April 27, 1995 (see Volpe National Transportation Systems Center in references).

agencies must determine if these applications are necessary for traffic management and if the public is willing to pay for these services either directly or indirectly.

Right-of-Way

Deployment of large scale land-line networks requires access to right-of-way for cable placement. Transportation agencies are uniquely endowed in this regard because they typically control right-of-way that spans wide geographic regions and are therefore well suited to deploy owned infrastructure or to provide access for private telecommunications networks. Nationally, the Interstate Highway System extends across more than 42,500 miles of roadway.

One option for transportation agencies is to leverage access to right-of-way in order to obtain communications capacity on a fiber network. These arrangements offer the opportunity for transportation agencies to obtain new services at little or no cost, and for private sector companies to expand networks.[140]

Several transportation agencies, including Bay Area Rapid Transit and the Missouri Highway and Transportation Department, have used right-of-way control to develop public-private partnerships for ITS. Case studies on these deployments are presented in chapter three. Many complexities arise in these arrangements including liability concerns, valuation of right-of-way, and potential legal obstacles.

Lease Versus Own

Transportation agencies also must decide whether to lease or own fiber networks. Several key decision factors are involved including cost, reliability, operations and maintenance, and resource availability. Among these, cost is usually the foremost decision factor. Leasing broadband capacity is very expensive and is often considered an inferior alternative to owning the

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[140] Right-of-way deals are sometimes preferred to obtaining new funding because a transportation agency may have the legal authority to develop public-private partnerships without legislative approval. However, an agency may find it desirable to interact with the legislature which may be very sympathetic to proposals to deploy new infrastructure that incur no cost to the state.

network. Leasing costs are also subject to fluctuation which can lead to unpredictable ongoing costs. However, transportation agencies should consider the total life cycle costs of deployment in deciding whether to lease or own.

Conclusions

Public agencies must consider both engineering and management issues in network deployments. The technical attributes of fiber systems are well known and understood. However, the managerial concerns are not clear cut and are highly dependent upon the unique needs and circumstances of individual state agencies.

Fiber is a superior alternative to other transmission mediums for broadband communications requirements. The technology exists and fiber deployments for government networks in Iowa, Missouri, Connecticut, Massachusetts, Texas, and California demonstrate wide scale adoption. The popularity of fiber for state networks can be attributed to its cost effectiveness and reliability. Non-proprietary standards such as SONET ensure system compatibility and extensibility. Arguably, fiber could become the standard backbone communications medium for state and local government communications networks.

APPENDIX B - ACRONYMS

APD	Avalanche Photo Diode
APTS	Advanced Public Transportation Systems
ATIS	Advanced Traveler Information Systems
ATM	Asynchronous Transfer Mode
ATMS	Advanced Traffic Management System
AVCS	Advanced Vehicle Control Systems
BART	Bay Area Rapid Transit
Bps	Bits per second
BRLC	Broadband Remote Line Concentrators
Caltrans	California Department of Transportation
CA/T	Central Artery/Tunnel
CCTV	Closed circuit television
CIO	Chief Information Officer
CNRI	Corporation for National Research Initiatives
ConnDOT	Connecticut Department of Transportation
COPs	Certificates of participation
CTPID	Center for Technology, Policy, and Industrial Development
CVO	Commercial Vehicle Operations
dB	decibels
DFB	Distributed Feedback Laser
DTI	Digital Teleport Incorporated
EPA	Environmental Protection Agency
FCC	Federal Communications Commission
FDDI	Fiber Distributed Data Interface
FEMA	Federal Emergency Management Administration
FHWA	Federal Highway Administration

Gbps	Giga bits per second
GPAC	Government Performance Audit Committee
Hz	Hertz
ICN	Iowa Communications Network
IDOT	Iowa Department of Transportation
IPTV	Iowa Public Television
IRMC	Information Resources Management Commission
ISDN	Integrated Services Digital Network
ITS	Intelligent Transportation Systems
ITTC	Iowa Telecommunications and Technology Commission
IVHS	Intelligent Vehicle Highway Systems
IXC	Inter-exchange carrier
kbps	Kilo bits per second
km	Kilometer
LAN	Local area network
LATA	Local access and transport area
LEC	Local exchange carrier
LED	Light emitting diode
Mbps	Mega bits per second
MFSNT	MFS Network Technologies
MHD	Massachusetts Highway Department
MHTD	Missouri Highway and Transportation Department
MISP	Motorist Information Systems Project
MIT	Massachusetts Institute of Technology
MTA	Massachusetts Turnpike Authority
NCDOT	North Carolina Department of Transportation
NCIH	North Carolina Information Highway

NII	National Information Infrastructure
nm	Nanometer
OC	Optical carrier (see Table A.4)
OTDR	Optical time domain reflectometer
PBCC	Pitney-Bowes Credit Corporation
PBX	Private Branch Exchange
PSTN	Public switched telephone network
RBOC	Regional Bell Operating Company
RFP	Request For Proposal
ROW	Right-of-way
RPCP	Research Program on Communications Policy
SJDST	City of San Jose Department of Streets and Traffic
SMDS	Switched multimegabit data service
SNET	Southern New England Telephone
SONET	Synchronous optical network
TCP/IP	Transmission control protocol/Internet protocol
TOS	Traffic Operations System
TSMP	Traffic Signal Management Project
TXDOT	Texas Department of Transportation
USDOT	United States Department of Transportation
WAN	Wide-area network

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