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Networking K-12 Schools:
Architecture Models and Evaluation of Costs and Benefits

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A.B., Computer Science, Harvard College (1990)

Submitted to the Sloan School of Management and
the Technology and Policy Program
in Partial Fulfillment of the Requirements for the Degrees of

MASTER OF SCIENCE IN MANAGEMENT

and

MASTER OF SCIENCE IN TECHNOLOGY AND POLICY

at the
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ABSTRACT

Network connectivity within K-12 schools is growing rapidly, spurred on by encouragement and financial support from the government and the private sector. Fanfare surrounding the Internet adds to schools' desire to develop networking infrastructure quickly. However, computer networking can be a vital technological tool to improve education only if all stakeholders clearly understand both the benefits and the costs of the technology.

This thesis examines the costs and the benefits of networks in K-12 schools. To examine costs, five technology models are developed with increasing levels of connectivity. For each model, a range of one-time and annual costs are computed. These costs are extrapolated to the national level to examine the costs to network all U.S. schools.

The data from the models indicate that the cost of the network hardware is only a small fraction of the overall networking costs. PC purchases, initial training, and retrofitting are the largest one-time costs for starting the network. The costs for the wiring and equipment are typically not as high. Support of the network is the largest ongoing annual cost that schools must face. Over the first five years, support and training together comprise 46% of the total costs of networking schools. Costs are significantly reduced when aggregated at the district and state levels due to increased purchasing power.

To examine the benefits of networking in K-12 schools, this thesis evaluates the use of a new product, Internet CNN NEWSROOM. Students using Internet CNN NEWSROOM placed more importance on the use of computers for schools projects than did other students with similarly high access to technology. A novelty effect accompanied the technology, in which initial excitement and extensive use of the product diminished over time. The greatest barrier to use of Internet CNN NEWSROOM effectively by teachers and students was a lack of training and support for this prototype service; this impediment highlights the need for school funding of human infrastructure in addition to network infrastructure. The study reveals a fundamental shift in students' opinion of a computer's purpose – from typing and gaming to information retrieval and communication.

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Table of Contents

1 Introduction 13

1.1 Introduction 13

1.2 Statement of Thesis 15

1.3 Synopsis of Findings 16

1.3.1 Costs 16

1.3.2 Benefits 18

1.4 Review of K-12 Networking Costs and Benefits Literature 20

1.5 Thesis Overview 27

2 Architecture Models and Costs 29

2.1 Introduction 29

2.2 Cost Models of K-12 Networking 30

2.2.1 Architecture of the District Network 32

2.2.2 Cost Areas 34

2.2.3 School Characteristics 35

2.2.4 Cost Models 37

2.2.5 Cost Comparison of Models 49

2.3 Potential Impact of Cost Reduction Initiatives 50

2.4 Summary 54

3 Educational Networking Benefits 57

3.1 Introduction 57

3.2 Educational Benefits 58

3.2.1 Benefits of Stand-Alone Computers in Education 59

3.2.2 Benefits of Educational Networking 60
3.2.3 Review of Technology Models 62
3.3 Product Background 64
3.3.1 CNN NEWSROOM 64
3.3.2 Internet CNN NEWSROOM 65
3.4 Experimental Protocol 66
3.4.1 Study and Control Groups 66
3.4.2 Evaluation Methodology 67
3.4.3 Demographic Factors 68
3.5 Product Evaluation Findings 69
3.5.1 User Feedback 69
3.5.2 Observed Novelty Effect 77
3.5.3 Effect on Technical Proficiency 82
3.5.4 Shift in View of Function of Computers 83
3.6 Summary 88

4 Policy and Product Recommendations 91
4.1 Introduction 91
4.2 Policy Recommendations 91
4.2.1 Focus on Significant Cost Items 91
4.2.2 Encourage State and District Level Purchasing 93
4.2.3 Develop Scalable Architecture 93
4.2.4 Support Initial Funding Barrier 94
4.3 New Product Recommendations 94
4.3.1 New Market Opportunity 95
4.3.2 User Interface 95
4.3.3 Product Features 96

4.4 Summary 97

Appendix 1 Internet CNN NEWSROOM Home Page 99

Appendix 2 Focus Group Protocol 101

Appendix 3 Survey 103

Appendix 4 Survey Responses 109

Bibliography 119

List of Tables

Table 1. PC Dialup Model Costs....38

Table 2. LAN with Shared Modem Model Costs....40

Table 3. LAN with Router Model Costs....42

Table 4. LAN with Local Server and Dedicated Line Model Costs....44

Table 5. Ubiquitous LAN with Local Server and High-Speed Line Model Costs....48

Table 6. Total One-Time and Ongoing Costs for Associated Models....49

Table 7. Total U.S. Costs (in $ Millions) for Model Four Level Connectivity....50

Table 8. Total Savings (in $ Millions) for Potential Cost Savings Programs....51

Table 9. Architecture Model Benefits....63

Table 10. Survey Response Rate....68

Table 11. User Responses to "What do you like most about Internet CNN NEWSROOM?"...73

Table 12. User Responses to "What do you like least about Internet CNN NEWSROOM?"...76

List of Figures

Figure 1. Star Network 32

Figure 2. Network Access of U.S. Public Schools 36

Figure 3. Single PC Dialup Model 37

Figure 4. LAN with Shared Modem Model 39

Figure 5. LAN with Router Model 41

Figure 6. LAN with Local Server and Dedicated Line Model 43

Figure 7. Breakdown of Costs for Model Four 45

Figure 8. Ubiquitous LAN with Local Server and High-Speed Line Model 47

Figure 9. Ongoing Costs Per Student Per Model 55

Figure 10. Startup and Ongoing Costs Per Student Per Model 55

Figure 11. Percentage of Accomplished Computer-Using Teachers Agreeing with the Following Statement 59

Figure 12. Computer Networking Benefits to Education Stakeholders 61

Figure 13. Desired Frequency of Internet CNN NEWSROOM Usage in the Classroom 78

Figure 14. Interest in Using Internet CNN NEWSROOM Features 79

Figure 15. Percent of Students Stating Computers are Good for Work 80

Figure 16. Percent of Students Using Computers at Least a Few Times a Week 81

Figure 17. Percent of Students Claiming "a Lot" or "Some" Experience with Computers 82

Figure 18. Percent of Students Claiming "a Lot" or "Some" Experience with the Internet 82

Figure 19. Percent of Students Claiming "a Lot" or "Some" Experience with the Web 83

Figure 20. Percent of Students Identifying Computers as Most Important Information Source 86

Chapter One

Introduction

1.1 INTRODUCTION

On a brisk sunny day last March in Northern California, U.S. President Bill Clinton stood perched atop a ladder, donning electrician's gloves, to install seventy feet of red, white, and blue category-five wire at Ygnacio Valley High School. Other top U.S. officials joining him in the task of wiring up schools included Vice President Al Gore, Education Secretary Richard Riley, Commerce Secretary Ron Brown, and FCC Chairman Reed Hundt. On that day, the administration unveiled its plan to couple $2 billion in federal grants with private donations to wire every classroom in the country by the year 2000.[1]

The federal government is not alone in its enthusiasm for networking K-12 schools.[2] State and local governments, teachers, parents, and corporate America have called for a greater effort to install telecommunications infrastructure within schools. With broad support from multiple constituencies, many schools have begun to take the plunge into implementation of information infrastructure. Several developments suggest that the rate of network connectivity among K-12 schools will continue to grow rapidly:

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[1] San Jose Mercury News (1996)

[2] K-12 schools include U.S. public and private schools with students in grades kindergarten through twelve.

- The federal government is committed to have every classroom in the U.S. connected to the National Information Infrastructure (NII) by the year 2000.
- A number of telephone and cable companies have announced plans to connect schools in their service areas at low or no cost.
- Modern, high-speed networks have been installed at a number of progressive, pioneering K-12 schools.
- The Internet, a global network of networks that connects an abundance of educational resources, is experiencing phenomenal growth.

However, to date, there is relatively little known about the costs and benefits of connecting schools to the information infrastructure. The lack of research in this area is distressing given the enormous financial and human resources that the public and private sectors are committing to K-12 networking. Just a few years ago, the lack of data in this area may have been justified due to the dearth of case studies; there were very few schools with networking infrastructure from which to gather cost and benefit data. However, in 1996, there exist a significant number of pioneering, early adopter schools that have installed and make use of information infrastructure. Therefore, it is imperative at this time to examine how these schools have successfully developed networking infrastructure, how much it has cost them to do so, and how the technology benefits them in their task of educating students.

Educators, school administrators, parents, politicians, community leaders, CEOs, regulators, and students all have a role in influencing the prominence that computer networking, and technology in general, are given in K-12 education. Cost and benefit data should be vital in forming policies governing the use of networking technology in education. It is hoped that this thesis will provide information to help formulate education and telecommunications policy in this country. As the information in this thesis becomes outdated, as it will in an age of rapidly

advancing technology, this study should provide a methodology for updating the information it contains.

1.2 STATEMENT OF THESIS

This thesis assumes that computer networking can improve education within schools. The unique capabilities of computer networks can make education more interesting and more effective. However, networking will have a net positive effect on education only if all stakeholders clearly understand both the benefits and the costs of the technology. Without a clear understanding of both benefits and costs, the implementation is unlikely to achieve its intended goals.

It is vital that stakeholders understand the technology's benefits and limitations. If they do not understand, they will reject the technology since it does not meet their misguided or excessive expectations. Oettinger (1969) describes numerous examples of the failure of technology in schools because the true features and benefits of the technologies were not clearly communicated to teachers and school administrators. If users of technology do not fully understand its features, they will be disappointed when they do not encounter the capabilities they expect and will be unaware of the capabilities that the technology does truly provide.

This condition is true especially in the case of K-12 school networking. Given the enormous publicity surrounding the Internet today, some people assume that networking can solve many of the resource constraints facing schools. While networking does provide unique capabilities to schools, it is vital that schools understand that Internet connectivity will not serve as a panacea for their educational, administrative, and financial problems.

It is also vital that stakeholders understand the true costs of the technology because insufficient budgeting for technology will ensure minimal and inefficient use of the technology. The true cost for technology exceeds the purchase price of hardware and software. Stakeholders must be aware of all cost factors including technology support, training, and administration.[3]

This cost augmentation is particularly true in the area of computer networking. Networking is a complex technology that requires professional technical support. Additionally, computer networking is a new technology paradigm; training is an essential cost item that will enable users to understand how to use networks effectively.

1.3 SYNOPSIS OF FINDINGS

1.3.1 Costs

This thesis attempts to enhance the use of educational networking by shedding light on the costs and the benefits of networks in K-12 schools. To examine costs, five technology models are developed. Each model represents a technical model for a school as it proceeds from a state of stand-alone computing to one of ubiquitous networking. These models, building on prior research, use empirical data from a sample of technologically advanced schools and school districts. For each model, a range of one-time and annual costs is computed. These costs are extrapolated to the national level to examine the total cost to network all U.S. schools.

The data from the models indicates that the cost of the network hardware is only a small fraction of the overall networking costs. PC purchases, training, and retrofitting are the largest one-time costs for starting the network. The costs for the wiring and equipment are typically

[3] Technology budgeting in the corporate world does consider the greater augmented cost. For example, recent Gartner Group PC cost-of-ownership studies show that five-year costs can exceed $40,000 per PC – the major cost component being PC administration and end-user support. (Business Wire, 4/10/95)

not as high. Support of the network is the largest ongoing annual cost. Over the first five years, support and training together comprise 46% of the total costs of networking schools.

The costs to network a school are complex and challenging to estimate. The costs for most schools will fall into a bounded range, but each particular school will vary greatly depending on its individual needs and characteristics.

There are two major discontinuities in the curve of increasing school networking. The first jump in cost arises when the school installs a local area network (LAN). The school and district must pay to have the LAN installed and employ full-time support staff. The second jump arises if and when the school decides to purchase enough PCs to support widespread concurrent network access. Currently, the number of networkable PCs in most schools is inadequate; there would be a significant cost to provide multiple PCs in every classroom in the U.S. In addition, many older schools will require expensive electrical and retrofitting work to support the increased number of PCs in the school. In the intermediate stages between these jumps, the costs are not as great.

The startup costs for the network increase at a faster rate than the annual ongoing costs as the network architecture complexity increases. The divergence indicates that the most significant hurdle a school will face is the initial investment costs in the network and computers.

Purchasing of technology equipment at the state and district levels can significantly reduce costs. Schools stand to save much money by pooling resources and purchasing power with other schools in the district and at the state level. When schools share a high speed data link or support staff, the costs per school drop considerably.

This research suggests that a number of programs would have a significant impact on the total networking costs. If all schools coordinate purchasing at the state level, cost savings at the national level could exceed $2 billion. If schools were given free Internet connectivity, the total annual costs for school Internet connections would be reduced by $150 - $630 million. However, since costs for telecommunications lines and services represent only 11% of the total costs, tariff rate reductions will have a relatively small impact.

Finally, as the costs of networking schools are better understood, a new question arises: how will these costs be financed? Many states have programs to fund networking in schools. The federal government has a role, although, as the administration says, the NII will be built by the private sector.[4] A number of states have initiated cooperative ventures between businesses and schools. An expansion of these programs may be the key for successfully networking K-12 schools.

1.3.2 Benefits

To examine the benefits of computer networking in K-12 schools, this thesis evaluates the use of a new networked multimedia information service, Internet CNN NEWSROOM, in Lexington High School. Students using the service were compared to two control groups that did not use Internet CNN NEWSROOM. As a new educational product, it is not surprising to find that the product contains technical glitches and is not well integrated into the curriculum. However, research based on focus groups and user surveys indicate that it provides valuable educational benefits in the classroom.

Internet CNN NEWSROOM generated a considerable novelty effect among student users. In their first few months of using the product, students expressed great enthusiasm about the product and displayed a sharp increase in technology usage. However, after the novelty effect

[4] Information Infrastructure Task Force (1994), p.2.

wore off student interest in Internet CNN NEWSROOM and attitude towards technology retreated from their formerly high levels.

Students using Internet CNN NEWSROOM placed more importance on the use of computers for schools projects than did other students with similarly high access to technology. These students also made increased use of computers and networks for school work and claimed to have a greater increase in experience with the Web than students without access to Internet CNN NEWSROOM.

While students using Internet CNN NEWSROOM placed more reliance on computers as the year progressed, students using technology but not Internet CNN NEWSROOM placed less reliance on computers over the same period. The former group, in using content-rich Internet CNN NEWSROOM, began to view computers as valuable for class work. The latter group, without access to Internet CNN NEWSROOM, was not able to find good information resources for school projects using computers.

The greatest barrier to use of Internet CNN NEWSROOM effectively by teachers and students is the lack of knowledge about using computers, the Internet and the Internet CNN NEWSROOM interface. User training is a necessary prerequisite for proper use of the technology. Although students complained about glitches in system performance, they were not excessively bothered by them.

The teacher and students stated that the video presentation of current events was much more powerful than text. However, while students expressed a great interest in using video clips from Internet CNN NEWSROOM for their research reports, most said that they were more difficult to use than text.

Users cited Internet CNN NEWSROOM's archive search capability as its single greatest benefit. Other key benefits of the Internet version include the quick access to the desired content. The teacher cited two other benefits – the ability to access all the content and accompanying material at a single Internet site and increased exposure to the Internet due to her experience with Internet CNN NEWSROOM.

This study indicates that there is a fundamental shift in the primary use of computers by students. Students who have not used the Internet or on-line services viewed computers as having three functions – word processing, typing instruction and game playing. On the other hand, more experienced computer users emphasized other more powerful uses for computers including information retrieval and communication.

1.4 REVIEW OF K-12 NETWORKING COSTS AND BENEFITS LITERATURE

Public debate over the role of technology in education has been manifest since the formation of a unified educational system in the U.S. in the 1920s.[5] Whitehead (1929) argues that the use of simple technology in the classroom can make education more effective. He extols the benefits of using technology – a surveyor's chain and compass – to supplement lectures in history and geography. However, he warns that "the provision of elaborate instruments is greatly to be deprecated." In his words, A. N. Whitehead was one of the first people in the modern age to recognize both the potential benefits and costs of technology in education.

Oettinger (1969) provides an early critique of computer technology in the classroom. He argues that instructional technology can lead to genuine improvements in technology only if it is at the

[5] As described in Olson, Jones & Bezold (1991), in the 1920s the government acted to consolidate the small one-room school houses that dotted the country into centralized school districts near population centers. The number of school districts was reduced from 150,000 to 17,000 as part of a national policy to unify and standardize education in the country.

behest of teachers and is accompanied by judicious planning and an understanding of its costs, benefits and limitations. He faults policy makers, consultants, administrators, and businesses for pushing technology without meeting these conditions.

The case of computer networking as an educational technology is no different. Oettinger's three prerequisites – planning, stakeholder buy-in, and an understanding of costs and benefits – are necessary for a successful network implementation. There is extensive research describing best practices for planning and achieving buy-in for technology in schools. Given the universal nature of these problems, the recommendations are relatively similar across all technologies including computer networking. However, research on the costs and benefits are particular to each technology. As stated above, the existing body of research on the costs and benefits of K-12 networking is inadequate. It was only in the past year that a few notable publications addressed the subject directly. This section will review eight recent publications that examine K-12 networking costs and benefits.[6]

Carlitz and Hastings (1994) responded to the recent launch of the NII as a policy set forth by the Clinton/Gore administration. They acknowledged that, of the NII stakeholders, schools have much to gain but are the least capable of understanding and integrating the new technology. Carlitz and Hastings responded to this need by developing a set of "stages of connectivity" through which schools could progress in connecting to the NII. The paper, while not a how-to manual, is directed at schools to provide them with basic technical and cost information to use in successfully developing infrastructure. The stages of connectivity outlined in the paper are:

1. Network gateways – i.e. bulletin board systems (BBS)
2. Internet dialup

[6] The publications are reviewed in chronological order since some of the later works derive from earlier work.

3. Serial Internet connections through serial line interface protocol (SLIP) or point-to-point protocol (PPP)
4. LAN connectivity through SLIP/PPP
5. Higher speed options, such as integrated service digital network (ISDN), leased lines, frame relay or switched multimegabit data service (SMDS)

For each of the connectivity stages, Carlitz and Hastings provide a brief technical description, with intermittent discussion of typical costs, along with a brief discussion of benefits and limitations. The paper provides an excellent introduction of networking issues to schools. It does not attempt to provide a systematic analysis of costs or benefits of K-12 networking, nor does it examine the policy issues faced by stakeholders.

Massachusetts Telecomputing Coalition (1994), also directed at school decision makers, develops six "K-12 Internet connectivity models":

1. Standalone Dialup
2. Shared Modem – school LAN shares a modem
3. LAN Gateway/Portage – school LAN has an information server
4. Standalone Peer Dialup – using SLIP/PPP
5. Network Model/Router
6. Desktop Internet – with a dedicated Internet connection

For each of the six models, the paper describes costs, services available, connectivity capabilities, appropriate user levels, and relative advantages and disadvantages. The paper demonstrates effectively that the lower models, while initially less expensive, are not scalable and are much more expensive when there are more than a handful of users. A connection choice decision guide provides the reader with an easy-to-use decision analysis tool to choose the ideal model for any school. The models developed in Massachusetts Telecomputing Coalition (1994) and in Carlitz and Hastings (1994) provided the basis for the development of the technology models in this thesis.

Rothstein (1994), a U.S. Department of Education working paper, represents the author's first analysis of K-12 networking costs. It developed architecture models based on Massachusetts Telecomputing Coalition (1994) and Carlitz and Hastings (1994). The report went further in using extensive empirical data to develop cost estimates for each of the models. It discussed the policy implications raised by those cost estimates. It did not examine the benefits of educational networking. This thesis presents the author's latest findings based, in part, on this initial research.

Barreca (1994) is a study done for the Telecommunications Technology Forecasting Group, whose advisory board includes representatives of major local and long-distance telephone companies. The paper summarizes the models and costs developed in Rothstein (1994). It argues that the costs would decrease for each of the models if schools were to use ISDN technology, a technology jointly developed by the telephone companies. The impetus for this paper was partly in response to the chapter in Rothstein (1994) that discouraged the use of ISDN in schools because of its high per minute usage rates and its inability to provide high-bandwidth connectivity above 378 kilobits per second (Kbps).[7]

Telecommunications Industries Analysis Project (1995) was commissioned by the Telecommunications Industries Analysis Project, a cross industry-government group with representatives from domestic and international telecommunications firms and state utility regulatory agencies. This report was also issued in response to Rothstein (1994). The paper examined the costs of broadband (i.e., greater than 45 megabits per second (Mbps)) networking, in contrast to Rothstein (1994) which did not go beyond wideband (1.5 Mbps) networking. The

[7] Changes in ISDN tariff rates in a few states over the past two years have addressed at least the former argument. However, in most states, ISDN rates are still exorbitantly high. See "A Steep Hurdle to Web Shortcut" (*New York Times*, 3/25/96, p. D1) that demonstrates that ISDN usage for Internet access costs hundreds or even a thousand dollars monthly in many areas of the U.S. The latter argument about bandwidth scalability and other issues including local ISDN monopolistic structures have not changed (see Rothstein (1994)).

report focused on the costs of local exchange carrier (LEC) network investment to provide broadband connectivity to all schools. Pricing of school network connectivity was not included because the current broadband pricing structure was prohibitively expensive for schools.

Telecommunications Industries Analysis Project (1995) compared the costs of networking schools in three different models:

1. Teacher-only access (1 PC per classroom) – $4-6 billion annually over five years; $0.2-1.2 billion annually over twenty years
2. Team-of-students access (7 PCs per classroom) – $10-12 billion annually over five years; $0.2-2.9 billion annually over twenty years
3. Universal access (26 PCs per classroom) – $27-31 billion annually over five years; $1-9 billion annually over twenty years

For each of the three models, the costs for software, Internet access, and network investment over a five-year and a twenty-year broadband deployment schedule were estimated. The report contains three major conclusions: school costs greatly exceed LEC network investment costs; accelerating deployment increases network investment costs; and the number of PCs per classroom did not effect the network investment costs. The report does not take into account the installed base of PCs in the classroom.

In contrast to the previous publications that focused on networking costs, U.S. Congress, Office of Technology Assessment (1995) provides an in-depth analysis of the benefits of networking, and technology in general, in K-12 schools. It finds that "communications technology is one of the biggest changes technology offers classroom teachers."[8] In a brief overview of networking cost issues, the report summarizes the findings of Rothstein (1994). In turn, this thesis elaborates on some of the networking benefits described in U.S. Congress, Office of Technology Assessment (1995).

[8] U.S. Congress, Office of Technology Assessment (1995), p. 2.

McKinsey (1995) is a pro bono project performed by McKinsey & Company, the management consulting firm, for the National Information Infrastructure Advisory Council (NIIAC).[9] The report outlines the benefits of NII connectivity, infrastructure options and costs, and the challenges to capturing the benefits. The report examines four infrastructure models:

1. Lab (one lab with 25 networked PCs per school) – $11 billion initially; $4 billion annually
2. Lab Plus (Lab plus one computer and modem per teacher) – $22 billion initially; $7 billion annually
3. Partial Classroom (1.5 Mbps connection, Ethernet LAN, half of classrooms have 1 PC per 5 students) – $29 billion initially; $8 billion annually
4. Classroom (all of the above plus all classrooms have 1 PC per 5 students) – $47 billion initially; $14 billion annually

All four models include a district server and LAN; school server and peripherals; professional development; and support. The deployment phase is five years for the first three models and ten years for the fourth model. The report's three major conclusion are as follows:

- Hardware purchase and installation constituted the largest one-time cost.
- Support and training costs were significant while connectivity costs were not.
- Video and voice networks could be added without much extra cost.

McKinsey (1995) developed a weighted average cost for each of the models. This methodology is different from the cost ranges developed in Rothstein (1994) and in this thesis. The report also includes costs for non-networking computing items such as printers and furniture.

[9] The National Information Infrastructure Advisory Council (NIIAC) was created by executive order at the end of 1993 and formally established and appointed in early 1994. The thirty-seven member advisory panel represents many of the key constituencies with a stake in the NII, including private industry; state and local governments; community, public interest, education, and labor groups; creators and distributors of content; privacy and security advocates; and leading experts in NII-related fields. The NIIAC has the responsibility of advising the Secretary of Commerce and the Administration on a national strategy for promoting the development of the NII and the Global Information Infrastructure (GII).