NIST GCR 03-859

Economic Impact of the Advanced Technology Program's HDTV Joint Venture

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January 2004

National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

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Prepared for
Economic Assessment Office
Advanced Technology Program
National Institute of Standards and Technology
Gaithersburg, MD 20899-4710

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Purchase Order NA1341-02-W-1415
January 2004

U.S. Department of Commerce
Donald L. Evans, Secretary

Technology Administration
Phillip J. Bond, Under Secretary for Technology

National Institute of Standards and Technology
Arden L. Bement, Jr., Director

Abstract

In 1995, the Advanced Technology Program (ATP) co-funded a high-definition television (HDTV) joint venture (JV) project. Sarnoff Corporation, a research and development firm with extensive experience in television technology, assembled a unique nine-firm JV team and led that team to an ATP award to investigate new approaches to creating and operating digital studios. Technological innovations from the project reduced the cost of the conversion to digital television (DTV) broadcasting for most television stations and quickened the introduction of new digital studio technologies.

The JV successfully developed new technologies for digital television broadcasting, particularly a system for processing compressed digital television signals and a new technology that enables more efficient operation of digital television transmitters. These technologies were subsequently commercialized by their developers and have entered into service at television stations around the country. In addition, the JV developed methodologies and new approaches to creating and organizing digital studios that have impacted global broadcasting research and development. Two key outcomes include the AgileVision system, an integrated video server and compressed bit-stream switcher for broadcast operations, and digital adaptive precorrection (DAP), a technology that prevents digital broadcast signals from bleeding over into adjacent channels.

The study estimates the following measures of performance of the combined public and private investment:

- Net present value (NPV) of net benefits (1995 base year and real 2002 dollars): $126 million to $205 million;
- Social rate of return: 24.9 to 28.6 percent;
- Benefit-to-cost ratio: 3.5 to 5.0.

The analysis covers the period from the original project start date in 1995 through 10 years into the future (2013). The measures reflect the estimated benefits to industry users of the ATP-funded technologies and to some JV members relative to ATP and industry research and development costs.

Acknowledgments

The authors would like to acknowledge the assistance of many on the ATP staff, especially our primary contacts Jeanne Powell and David Hermreck. Jeanne provided RTI with project documents needed for our study, reviewed deliverables for accuracy and readability, and coordinated this report's internal review at ATP. David contributed much of the technical background for the study as well as a great deal of information about the individual firms and their digital video technology development projects. Stephanie Shipp, Elissa Sobolewski, Barbara Cuthill, and Brian Belanger reviewed intermediate documents and the final report and provided valuable feedback.

We would also like to thank the joint venture's company representatives who provided a wealth of information. Frank Marlowe with Sarnoff Corporation provided background information on the joint venture's goals and strategies and technology outcomes. Several other investigators were extraordinarily helpful, including Brett Jenkins with Thales Broadcast and Media, Jerry Berger with AgileVision, Ruud Bolle and Chris Ward with IBM, and Tom Jacobs with Sun Microsystems. These investigators gave both their time and energy to ensure accurate portrayals of technology outcomes.

Our characterization of the use of JV-developed technologies was enabled by information provided by many public and commercial television stations. Among the many participants, we would like to acknowledge: Stacey Decker and Mike Johnson with South Dakota Public Broadcasting; John Duffy with WCNY-TV (Syracuse, NY); Gil Maxwell with Maine Public Broadcasting; Bill Ziegler with WLVT-TV (Lehigh Valley, PA); and Steve Zimmerman with WKOW-TV (Madison, WI).

We would also like to extend our appreciation to Andrea Drost with The Association of Public Television Stations who provided invaluable research assistance.

Executive Summary

The Federal Communications Commission (FCC) is requiring studios at U.S. television stations to convert their operations from analog to digital systems. According to the FCC, “the digital transition will increase efficient use of the spectrum, expand consumer choice for video programming, and increase the amount of spectrum available for public safety and other wireless devices” (FCC, 2003a). Analog television broadcasting uses signal modulation techniques that require more of the spectrum because empty channels are left between each co-located broadcast signal to prevent those signals from interfering with one another. Digital broadcasting allows the FCC to permit adjacent channel broadcasting, thereby freeing up portions of the spectrum for other valuable uses.

This conversion has profound implications for the cost and organization of studio operations. Under the analog broadcasting paradigm, broadcasters replaced or upgraded their existing studio equipment on an as-needed basis. But the digital conversion entails a complete overhaul of studio equipment and operations as the technologies to manipulate and pass through digital signals are different from those required for analog. The Advanced Technology Program (ATP) co-funded high-definition television (HDTV) joint venture (JV) led to new technological innovations that reduced the cost of the conversion to digital television (DTV) broadcasting for most television stations and quickened the introduction of new digital studio technologies.

Sarnoff Corporation, a research and development (R&D) firm with expertise in digital television technology, assembled a unique team and led that team to an ATP award to investigate new approaches to creating and operating digital studios. Sarnoff assembled a cross-functional team of broadcasting and information technology industry leaders to develop the requisite technologies. Participation from such a broad array of firms was deemed essential, as potential individual technology outcomes did not, according to participants, "make sense" on their own. For any resulting technology to be truly viable, it needed to coordinate well and be interoperable with other studio technologies. The JV leveraged the individual competencies of each member to create a whole greater than the sum of its parts.

ES.1 THE HDTV JOINT VENTURE TECHNOLOGY OUTCOMES

The JV successfully developed new technologies for DTV broadcasting, particularly a system for processing compressed DTV signals and a new technology that enables more efficient operation of DTV transmitters. These technologies were subsequently commercialized by their developers and have entered into service at television stations around the country. In addition, the JV developed methodologies and new approaches to creating and organizing digital studios that have impacted global broadcasting R&D.

The importance of these technologies has been recognized through receipt of several prestigious awards. Successful development of the transmitter technology earned Thales Broadcast & Media an Emmy Award for Technical Excellence from the Academy of Motion Picture Arts and Sciences in 2003. AgileVision's compressed video processing system, the AGV-1000, has garnered several emerging technology awards since its release, including those from Broadcast Engineering and the National Association of Broadcasters (NAB).

The JV's research, development, and commercialization outcomes are summarized in Table ES-1. The JV set for itself seven technical goals, all of which were successful, though only five of the accomplishments have been incorporated into commercial products. Those that have not found full-scale

Table ES-1. JV Technology Outcomes and Current State of Commercialization

Goal Index	JV Goal	Investigator(s)	Presently Commercialized?	Commercialization Vehicle
1	Encoding and transcoding technology to manipulate the highly compressed HDTV pictures that will be used in the studio	Sarnoff Thomson	Yes	Integrated into the AgileVision system and some Thomson encoders.
2	Compressed bit stream switching technology for splicing, edits, cuts, and spatial effects	Philips Sarnoff AgileVision	Yes	Integrated into the AgileVision system.
3	Digital server technology capable of providing multiple compressed HDTV video streams with highly demanding quality of service constraints and high reliability	Advanced Modular Systems (AMS) Sarnoff SGI	Yes	Integrated into the AgileVision system.
4	Digital adaptive precorrection technology prior to transmission to accommodate the sensitivities to nonlinear power amplification of eight-vestigial sideband (8VSB) coded signals	Thales	Yes	Integrated in Thales digital transmitters; induced innovation in other transmitters.
5	Network interface to permit studios to be connected to external resources over wide area networks (WANs)	WorldCom	Yes	Network interface device developed and in service.
6	Browser and query technologies to permit content addressable retrieval of data	IBM	No	Some technology transfer through consulting agreements.
7	Distributed single-wire control and file transfer architecture to mange studio components under the direction of a master control workstation	IBM Sarnoff Sun Microsystems	No	Sun: briefly had products available. IBM: some technology transfer through consulting agreements.

Source: NIST, 2001.

commercial outlets have still had an impact. For example, IBM and Sun Microsystems both indicated that their R&D efforts (goals six and seven in Table ES-1) are molding approaches to new product development efforts.

This study quantifies the economic impact of goals one through four. The first three goals are incorporated in the AgileVision system, an integrated file server and compressed video stream management tool marketed to the nation's public television (PTV) stations. AgileVision delivers to its users onetime benefits consisting of reduced equipment costs and faster installation turnaround. Ongoing benefits stem from fewer labor hours required to operate the AgileVision unit compared to alternative studio installations with more equipment pieces.

The fourth technology outcome, Thales Broadcast & Media's Digital Adaptive Predistortion[1] (DAP) had similar onetime and ongoing benefits. The transmitter more easily met FCC spectral requirements than did competitor products, allowing end users to reap routine maintenance benefits and avoid costly filtering. End users also avoided the need to purchase more powerful transmitters to compensate for losses associated with installing more powerful filtering technologies. Thus, the transmitters were more cost effective. Furthermore, other transmitter manufacturers innovated to compete with Thales' technological innovation.

JV members unanimously agree that the project was a productive and valuable experience. Members indicated that the technologies they developed during the course of the JV would not have been developed in the absence of the JV and ATP funding, or if so, not as quickly. Without NIST ATP funding, Sarnoff doubts that JV members would have expended the resources to develop these technologies, let alone make the effort to perform the research jointly. The venture was able to generate significant synergy through facilitation of communication and knowledge exchange

ES.2 SUMMARY MEASURES OF ECONOMIC PERFORMANCE

The HDTV JV is evaluated as a suite of technologies. As such, the total quantifiable public and private economic benefit from JV technology outcomes is compared to the costs for the entire JV. The JV was funded at 48 percent cost-share with JV members. In all, the JV cost $58 million, of which ATP provided $28 million. The balance of funds, $30 million, was provided by the JV members. The costs included direct and indirect labor expenses as well as equipment, travel, and materials costs (NIST, 2003; NIST, 1999).

[1] Digital Adaptive Predistortion was later renamed Digital Adaptive Precorrection to better convey the value of the technology. Both terms are used in this report.

To quantify the economic benefit of the HDTV JV, the analysis compared the actual situation of producers and customers of JV technologies to a hypothetical scenario in which the JV did not exist. In the absence of the JV's AgileVision and DAP, this analysis argued that PTV licensees would adopt more costly studio installations and all DTV stations would use less efficient digital transmitters.

Table ES-2 summarizes the time series of costs, benefits, and net benefits for a range of JV technology market penetration rates. The range was necessary as the analysis proceeded using three hypothetical penetration rates for the AgileVision system in the PTV market. In all, net benefits range from $349 million to $526 million.

The estimated net benefits to industry from the program exceed the JV's investment costs for both the lower and upper bounds of our estimate. The NPV of net benefits lies between $126 million and $205 million. The benefit-to-cost ratio is between 3.5 and 5.0. The social rate of return is between 24.9 and 31.7 percent.

Table ES-2. Time Series of Costs, Benefits, and Net Benefits, 1995–2013, and Measures of Economic Return

	Net Benefits		
Year	**Low (thousands of dollars)**	**Midpoint (thousands of dollars)**	**High (thousands of dollars)**
1995	–2,600	–2,600	–2,600
1996	–17,500	–17,500	–17,500
1997	–14,200	–14,200	–14,200
1998	–13,600	–13,600	–13,600
1999	–3,900	–3,900	–3,900
2000	–8,900	–8,900	–8,900
2001	5,200	5,300	5,300
2002	18,000	18,000	18,000
2003	68,800	104,100	137,800
2004	46,300	51,600	58,300
2005	30,200	35,500	40,800
2006	30,200	35,500	40,800
2007	30,200	35,500	40,800
2008	30,200	35,500	40,800
2009	30,200	35,500	40,800
2010	30,200	35,500	40,800
2011	30,200	35,500	40,800
2012	30,200	35,500	40,800
2013	30,200	35,500	40,800
Total	349,700	438,000	526,200
NPV of Net Benefits (1995–2013)[a]	126,400	165,900	205,200
Benefit to Cost Ratio	3.47	4.24	5.00
Social Rate of Return	24.9%	28.6%	31.7%

Note: All net benefit values are expressed in real, 2002 dollars. Sums may not add to total due to rounding.

[a]To compute NPV, net benefits were discounted to 1995, using a 7 percent annual discount rate.

Source: RTI estimates.

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Abbreviations and Acronyms

8VSB	eight-vestigial sideband
AMS	Advanced Modular Systems
APTS	Association of Public Television Stations
ATM	Asynchronous Transfer Mode
ATP	Advanced Technology Program
BLS	Bureau of Labor Statistics
CEA	Consumer Electronics Association
CPB	Corporation for Public Broadcasting
CPI	Consumer Price Index
DAP	digital adaptive predistortion (precorrection)
DARPA	Defense Advanced Research Projects Agency
DPT	Digital Public Television
DTV	digital television
DV	digital video
EAO	Economic Assessment Office
EBS	emergency broadcasting system
FCC	Federal Communications Commission
HDTV	high-definition television
IT	Information Technology
JV	joint venture
kW	kilowatt
MPBC	Maine Public Broadcasting Corporation
MPEG-2	Moving Picture Experts Group, Version 2

NAB	National Association of Broadcasters
NBC	National Broadcasting Company
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NJN	New Jersey Network
NPV	net present value
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
O&M	operations and maintenance
OES	Occupational Employment Statistics
PBS	Public Broadcasting Service
PSIP	Program and System Information Protocol
PTV	public television
R&D	research and development
ROI	return on investment
RTAC	Real-Time Adaptive Correction
SD	standard definition
SDPB	South Dakota Public Broadcasting
SDTV	standard-definition television
SGI	Silicon Graphics Inc.
SMPTE	Society of Motion Pictures and Television Engineers
WANs	wide area networks

1 Introduction

Over the past half century, economists and other social scientists have convincingly demonstrated the importance of technological change in improving the standard of living. When a firm or an individual produces a technological change that improves the quality of a product or reduces the cost of making it, the overall level of economic well-being is increased. Likewise, when a new product or service is developed, the standard of living is improved as long as some consumers are willing to pay more than the costs of producing it. Established principles of welfare economics argue that the private level of investment in such innovations will be optimal in the absence of market failures or externalities; that is, if the innovator is able to fully appropriate benefits generated by the improvement.

In most cases, however, a portion of this economic benefit "spills over" to consumers or to other economic agents (Mansfield et al., 1977; Scherer, 1999), because the innovating firm or individual typically cannot fully recover the surplus created. If there is sufficient competition among producers, a "market spillover" may be created as prices fall to the point that the innovating firm can recover only a portion of its investments in research, development, or purchase of long-lived assets. In other cases, benefits may accrue to competitors and firms in related or unrelated fields, a phenomenon known as "knowledge spillover."

1.1 GOVERNMENT'S ROLE IN SUPPORTING RESEARCH AND DEVELOPMENT

The situation for research and development (R&D) aimed at producing or improving private goods and services is quite different from the creation of scientific and technological knowledge, the goal of most basic and applied research. In the latter case, it becomes difficult or impossible for innovators to achieve the major portion of the benefit from their inventions. Standard welfare economics tells us that private markets will yield a sub-optimal level of these goods, leading to a lower than desirable level of technical progress.

To correct for this potential market failure, a large number of government organizations provide funding for research activities. These entities, including such giants as the National Science Foundation (NSF), the National Institutes of Health (NIH), and the Defense Advanced Research Projects Agency (DARPA), fund in-house research activities, university research programs, and corporate projects and joint ventures. Governmental support for technology infrastructure and standards development is provided by the National Institute of Standards and Technology (NIST) and related organizations.

NIST's Advanced Technology Program (ATP) was created in 1990 to promote the development of risky technologies where market failures or externalities are likely to lead to under-investment by private firms. ATP funds, on a cost-sharing basis, pre-commercial R&D into new technologies and process improvements where substantial spillovers are expected and where technical and investment recovery risks are high.

1.2 EVALUATING THE EFFECTIVENESS OF ATP PROJECTS

Since its inception, ATP's Economic Assessment Office (EAO) has taken an active role in supporting evaluation of its funded projects, and to date, more than a dozen external assessments have been completed and shared with the public. These studies have measured the impact of the ATP on U.S. firms, industrial sectors, and the overall economy. The studies that ATP has conducted and funded include

- real-time evaluations of project progress, using ATP's project management teams and analysis of the data reported by the companies through the business reporting system;
- surveys of the participating companies to assess ATP's effect on the companies' decisions and success;

- project case studies that assess the costs and benefits of ATP's investments in specific technologies or technology areas;
- general studies of how ATP funding leads to spillover benefits to beneficiaries other than the ATP award recipients; and
- models that link large-scale macroeconomic models with microeconomic project analyses.

Case studies are an important part of ATP's economic analysis strategy. They provide an in-depth view of how ATP-funded technologies lead to economic benefits for the awardees, other companies, and consumers. Case studies also provide qualitative details about how ATP funding affects the investment decisions of companies and the success of the projects. Ideally, case studies provide credible quantitative estimates of the economic performance of ATP's investments in these technologies.

1.3 ATP'S INVESTMENT IN DIGITAL VIDEO

The emergence of Digital Video (DV) technology is an excellent example of the potential for new products and services to improve the standard of living, and of ATP's support for development of promising, high-risk technologies. DV offers opportunities to fundamentally improve the way information is exchanged, making it easier to access at lower cost and through the most effective media. It has the potential to enhance communications among individuals and organizations and can add to the enjoyment consumers derive from many forms of entertainment. DV includes all applications of digitized moving pictures (television, motion pictures, video, and animation), as well as extensions to these applications (Hermreck and Omidvar, 1997).

Recognizing this potential for DV to offer broad-based gains to U.S. society through productivity gains and quality-of-life improvements to consumers, ATP developed and managed a focused program entitled "Digital Video in Information Networks" from 1995 to 2000. The goal of the program was to increase the number of successful DV projects and accelerate the development and diffusion of DV and multimedia information and entertainment services that can be delivered over an interoperable information infrastructure for commercial, government, and personal use.

1.4 THE HIGH-DEFINITION TELEVISION JOINT VENTURE

One of the key components of the focused program in Digital Video was the co-funding of a joint-venture (JV) in high-definition television (HDTV) broadcast technology. The JV's goal was to develop a comprehensive suite of technologies to enable efficient digital studio operations. At the time the JV was conceived, digital television stakeholders were focusing their efforts primarily on adopting a digital television standard for terrestrial broadcasting based on Moving Picture Experts Group, Version 2 (MPEG-2) compression. Essentially, their efforts were focused on the efficient delivery of digital television (DTV) signals to the home. However, Sarnoff believed that "considerable effort would also be needed to achieve a cost-effective flexible HDTV studio and that such a studio should be based on compression technology to help manage the very high data rates required for [digital television]" (NIST, 2001).

The economic relevance of the JV's efforts was significantly enhanced by the Federal Communications Commission (FCC) decision to mandate conversion to DTV broadcasting. This decision requires studios at U.S. television stations to convert their operations from analog to digital systems. According to the FCC, "the digital transition will increase efficient use of the spectrum, expand consumer choice for video programming, and increase the amount of spectrum available for public safety and other wireless devices" (FCC, 2003a). Analog television broadcasting uses a larger portion of the spectrum because empty channels are left between each co-located broadcast signal to prevent those signals from interfering with one another. Digital broadcasting will allow the FCC to permit adjacent channel broadcasting, thereby freeing up portions of the spectrum for other uses. Digital broadcasting also allows far more information content in each channel, either providing much higher quality or multiple programs in a single broadcast "channel."

This conversion has profound implications for the cost and organization of studio operations. Under the analog broadcasting paradigm, broadcasters replaced or upgraded their existing studio equipment on an as-needed basis. But the digital conversion entails a complete overhaul of studio equipment and operations as the technologies to manipulate and pass through digital signals are different from those required for analog.

1.5 RESULTS OF THE JV AND RTI'S CASE STUDY EVALUATION APPROACH

The ATP co-funded HDTV JV led to new technological innovations that reduced the cost of the conversion to DTV broadcasting for most television stations and quickened the introduction of new digital studio technologies. Sarnoff Corporation, an R&D firm that was a central innovator in developing the DTV standard later adopted by the FCC, assembled a unique team and led that team to an ATP award to investigate new approaches to creating and operating digital studios.

The JV successfully developed new technologies for DTV broadcasting, particularly a system for processing compressed DTV signals and a new technology that enables more efficient operation of DTV transmitters. These technologies were subsequently commercialized by their developers and have entered into service at television stations around the country. In addition, the JV developed methodologies and new approaches to creating and organizing digital studios that have impacted global broadcasting R&D.

To quantify the economic benefit of the JV project, this analysis compares the *actual* situation of producers and customers of products embodying JV technologies to a *hypothetical* situation that would have existed in the absence of the JV. This analysis approach is known as a "counterfactual scenario." The report develops a detailed counterfactual world and describes the conditions that would arise and presents evidence supporting the counterfactual. Specifying the counterfactual scenario is essential to determining the information that will be needed to estimate the social benefits of the JV project. Once the counterfactual is specified and data collected, this analysis employs economic theory and quantifies the JV's benefits.

1.6 ORGANIZATION OF THE REPORT

The remainder of this report discusses the technology outcomes of the JV, describes how JV technologies impacted DTV conversion, and presents the quantitative results from an economic analysis of commercialized JV technologies. The report is organized as follows.

Section 2 provides an overview of the JV and its members, presenting qualitative results on JV technology outcomes. Within the JV, each member was tasked with R&D of a constituent component of the hypothesized DTV studio of the future. This section concludes by leveraging the discussion of technology outcomes to identify those technologies whose economic benefits to society can be quantified.

Section 3 presents the economic methodology for evaluating the quantitative success of the JV. This section discusses the technical and economic impact metrics that permit the evaluation of the JV relative to its counterfactual scenario.

Section 4 presents the results of the quantitative analysis and calculates measures of performance. The JV is analyzed as a portfolio; therefore, the benefits of commercialized technologies are compared to the JV's total costs. To evaluate the JV's effectiveness, the analysis also calculates several measures of performance, including the benefit-to-cost ratio, social rate of return, and present value of net benefits.

Finally, Section 5 of this report brings the analysis full circle: returning to the JV technologies, placing them in the broader context of their impact on the R&D activities of the broadcast equipment industry and the DTV conversion. The report concludes by looking forward to the potential benefits JV technologies may yield in the future.

2 Overview of the HDTV Joint Venture Project and Technology Outcomes

The high-definition television (HDTV) joint venture (JV) project led to new technological innovations that reduced the cost of the conversion to digital television (DTV) broadcasting for most television stations and quickened the introduction of new digital studio technologies. Sarnoff Corporation, a research and development (R&D) firm with expertise in video and broadcasting equipment, assembled a unique team in the form of a JV to investigate new approaches to creating and operating digital studios. The National Institute of Standards and Technology's (NIST's) Advanced Technology Program (ATP) awarded the JV additional funding support, thereby making the research effort a joint ATP and JV project. This section provides an overview of the project, its goals, and its technology outcomes. It also identifies the underlying drivers leading to the JV's formation and charts and evaluates the JV's pathway to success.

It is important to note that the scope of DTV broadcasting has broadened beyond HDTV to include standard-definition television (SDTV), DTV whose quality exceeds that of today's analog broadcast television but does not have the same high resolution of HDTV. Throughout this report, DTV includes both HDTV and SDTV. However, this report maintains the "HDTV project" title given to the project by ATP and the JV members.

2.1 THE HDTV JOINT VENTURE PROJECT

The national conversion to DTV broadcasting required U.S. television stations to initiate digital transmission operations no later than mid-2003. According to the Federal Communications Commission (FCC), "the digital transition will increase efficient use of the spectrum, expand consumer choice for video programming, and increase the amount of spectrum available for public safety and other wireless devices" (FCC, 2003b). Analog television requires a much wider spectrum allocation because empty channels must be left between co-located broadcast signals to prevent signals from interfering with one another. Digital broadcasting will allow the FCC to permit adjacent channel broadcasting, thereby freeing up significant portions of the spectrum for other uses. The ATP award that enabled the HDTV JV preceded the adoption of the FCC standard by approximately one year.

The conversion to DTV broadcasting has profound implications for the cost and organization of studio operations.[1] Under FCC rules, broadcasters are not required to install new digital studio equipment; they can meet FCC digital broadcasting requirements by converting their analog signals to digital. However, many broadcasters are investing in digital technology for their broadcast studio as part of their DTV broadcasting strategies. Under the analog broadcasting paradigm, broadcasters replaced or upgraded their existing studio equipment on an as-needed basis. But the digital conversion planned by many stations entails a complete overhaul of studio equipment and operations as the technologies used to manipulate and pass through digital signals are different from those required for analog.

Digital studio conversion is costly, not only in terms of equipment costs, but also in terms of installation, operations, and maintenance. Commercial stations faced a May 1, 2002, deadline, and public television (PTV) stations, a May 1, 2003, deadline to commence transmission operations in digital. Both deadlines passed with many stations not being on air because of construction delays and funding issues, among other types of

[1] Not all broadcasters chose to install new digital studio equipment; many broadcasters are converting their analog signals to digital using conversion equipment to meet FCC requirements.

setbacks. Regardless of individual station adherence to the deadlines, while commencing DTV transmission, broadcasters maintained their analog signal on air because the overwhelming majority of television audiences still use analog technology to view programming. Maintaining both digital and analog transmission operations places financial pressures on all stations' operating and facilities budgets.

The situation was further complicated by the fact that as the DTV broadcasting conversion commenced, digital equipment had yet to achieve satisfactory performance specifications. In the early 1990s, efforts were concentrated on creating digital transmission standards for the delivery of a digital broadcast signal to the home and less so on the innovation that would be required to create effective technologies for managing the digital studio that would create and transmit that signal (Dickson, 1995).

These technology and business drivers converged to form a case for the development of a coordinated strategy for new technologies for DTV broadcasting. The technology driver for more efficient studio technology and the business driver for cost-effective solutions led Sarnoff to create a JV to investigate new technologies for managing and accomplishing digital studio operations.

Integral to the proposed JV was the assembly of a cross-functional group of digital studio equipment suppliers that would leverage synergies from coordinated R&D. In the words of Frank Marlowe of Sarnoff, "The aim of [the JV] is to drastically reduce the cost of … equipment so that the [broadcasting] industry can move forward as rapidly as possible…. Until the technology is developed and made cost effective, there will not be an HDTV broadcasting business" (Dickson, 1995).

2.1.1 Rationale for ATP Involvement

DTV broadcasting deadlines catalyzed R&D efforts to make the conversion both efficient and more economically viable for stakeholders. NIST's ATP was uniquely positioned to organize and support these R&D efforts. ATP competitively selects high-risk, high-reward ventures that may yield significant social and economic benefits. ATP has funded several projects through its focused program "Digital Video in Information Networks" that funds projects to develop technological innovations aimed at increasing the national digital video technological infrastructure (ATP, 2003). When the JV was envisioned, it was seen as an opportunity to energize national DTV conversion and enhance U.S. competitiveness in the broadcast-technology sector (Yoshida, 1998).

ATP's commitment to the development of new DV technologies provided an avenue for Sarnoff and its JV team to receive third party support for its vision of a new, more economical model for managing digital broadcasting operations. Furthermore, ATP provided support to a research venture that would otherwise not have been funded.

2.1.2 HDTV JV Project Research and Development Goals

The project's goal was to develop and commercialize a comprehensive suite of technologies to enable efficient DTV and HDTV studio operations. At the time the project was conceived, DTV stakeholders were concentrating on adopting a DTV standard for terrestrial broadcasting based on Moving Picture Experts Group, Version 2 (MPEG-2) compression. Essentially, stakeholders focused their efforts on the efficient delivery of HDTV to the home. However, Sarnoff believed that "considerable effort would also be needed to achieve a cost-effective flexible HDTV studio and that such a studio should be based on compression technology to help manage the very high data rates required for HDTV" (NIST, 2001).

Studio technologies available in the mid-1990s lacked the capability to efficiently and economically manage HDTV's enormous data streams—1.5 gigabytes per second when decompressed. Video feed is either locally originated at the studio or distributed in compressed form by networks via satellite to the studio. Conventional technologies require stations to decompress satellite feed to perform studio manipulations, including video edits and insertions. In addition, if the feed is not to be aired immediately, it must be stored locally. According to Sarnoff, bandwidth, or data-throughput capacity, was very expensive in the early 1990s and therefore was a significant roadblock to DTV conversion. At that time, technologies did not exist that could transfer or store uncompressed data streams efficiently.

Sarnoff recognized that substantial technological innovations would be required to provide digital studios with equipment that could perform studio operations without the necessity of decompressing the content distributed by television networks. The JV envisioned a new breed of broadcasting studio and established technical objectives to produce innovative technologies that would permit processing, distribution, control, data management, and broadcast of compressed video streams. The individual studio components that comprise the JV's technical objectives are summarized in Table 2-1.

Table 2-1. JV Project Studio Component Objectives

Technology for encoding (compression) and transcoding (changing compressed format) HDTV video
Compressed bit stream switching technology for splicing, edits, cuts, and spatial effects
Digital server technology capable of providing multiple compressed HDTV video streams with highly demanding quality of service constraints and high reliability
Distributed single-wire control and file transfer architecture to manage studio components under the direction of a master control workstation
Browser and query technologies to permit content-addressable retrieval of data
Digital adaptive predistortion (precorrection) technology used in the final transmission amplifier to accommodate FCC requirements for nonlinear power amplification of eight-vestigial sideband (8VSB) coded signals
Network interface to permit studios to be connected to external resources over wide area networks (WANs)

Source: NIST, 2001.

2.1.3 Organization and Mechanics of the HDTV JV

Sarnoff assembled a cross-functional team of broadcasting and information technology industry leaders to develop the requisite technologies. Participation from such a broad array of firms was deemed essential, as potential individual technology outcomes did not, according to participants, "make sense" on their own. For any resulting technology to be truly viable, it needed to coordinate well and be interoperable with other studio technologies. The JV leveraged the individual competencies of each member, such as broadcast equipment R&D, networking, signal processing, and advanced computing, to create a whole greater than the sum of its parts. Each member was able to contribute its domain expertise at periodic meetings and through reviews of each member's research progress. The original JV group comprised nine firms (see Table 2-2), though Sarnoff invited additional firms to fill gaps in technical competency as nonmembers through subcontracts or informal relationships.

Table 2-2. JV Members and Years of Participation

Firm	Years of Participation	Participation Status
Sarnoff Corporation	1995–2000	JV Leader
Thales Broadcast & Media[a]	1995–2000	JV Member
IBM	1995–2000	JV Member
Thomson Electronics	1995–2000	JV Member
Sun Microsystems	1995–1998	JV Member
NBC	1995–1998	JV Member
MCI	1995–1998	JV Member
Philips Electronics	1995–1999	JV Member
Advanced Modular Systems (AMS)	1995–1997	JV Member
New Jersey Network (NJN)	1999–2000	JV Member
Wegener Communications	1999–2000	Inactive member
Silicon Graphics Inc. (SGI)	1998–2000	Nonmember participant; Replaced AMS
AgileVision	1999–2000	Nonmember participant

[a]Comark Communications was the original name of this JV member. During the course of the JV, the entity's name changed from Comark Communications to Thomcast following a merger. The entity is now known as Thales Broadcast & Media.

Source: NIST, 2001.

The JV project ran from late 1995 through 2000. Although the project was originally scheduled to run 3 years, it was extended an additional 2 years to adapt to changing technological and market conditions and to accommodate operational trials of technology outcomes. Though JV members and ATP concurred that the project changes were necessary, the project remained consistent with its original technical plan and total project budget (NIST, 2001). It became apparent to JV members that a test bed for R&D outcomes would be highly beneficial, and the New Jersey Network (NJN), a public television (PTV) licensee, was recruited by Sarnoff to join the team. The addition of 2 years allowed the JV to refine its technologies by leveraging technical developments occurring outside of the JV and in reaction to emerging market conditions. The JV recognized the opportunity to collapse many of the individual devices into a single high-performance computer.

Sarnoff formed AgileVision, a second JV co-owned by Mercury Computer Systems, a manufacturer of ultra high performance parallel computer systems. AgileVision did not join the JV officially, yet became the commercialization outlet for much of the JV technology.

ATP provides funding on a cost share basis; JV members must provide more than 50 percent of total JV funding. In this instance, JV members provided 52 percent of the JV's total funding, or $30.1 million, and ATP provided the remaining funds, $28.4 million. Total R&D expenditures were therefore $58.5 million.

2.2 TECHNOLOGY OUTCOMES

The JV set for itself seven technical goals, all of which were met successfully, though only five of the accomplishments have been incorporated into commercial products. The project's R&D outcomes are summarized in Table 2-3. Those that have not found full-scale commercial outlets could yet have an impact. For example, IBM and Sun both indicated that their R&D efforts (goals six and seven in Table 2-3) are molding approaches to new product development efforts in other areas. This section provides a general picture of individual JV member efforts, the degree of success, and the current state of commercialization for those efforts. It analyzes member comments and identifies social and economic benefits.

2.2.1 Sarnoff Corporation

Sarnoff led the overall system design and system integration for the project. Additionally, Sarnoff co-developed several technologies with other JV members. These efforts were most concentrated on the development of two technologies: compressed bit stream switching for splicing, edits, cuts, and spatial effects and a server technology to provide multiple compressed HDTV streams with demanding quality-of-service constraints. (The other technologies in which Sarnoff was involved are discussed under the headings of their teaming partners.)

The compressed bit stream switching technology allows end users to pass compressed digital signals through their digital studios while inserting local content and logos and performing basic manipulations. The technology removes the need to decompress

Table 2-3. Technology Outcomes and Current State of Commercialization

Goal Index	Project Goal	Investigator(s)	Presently Commercialized?	Commercialization Vehicle
1	Technology for encoding (compression) and transcoding (changing compressed format) HDTV video	Sarnoff Thomson	Yes	Integrated into the AgileVision system and some Thomson encoders.
2	Compressed bit stream switching technology for splicing, edits, cuts, and spatial effects	Philips Sarnoff AgileVision	Yes	Integrated into the AgileVision system.
3	Digital server technology capable of providing multiple compressed HDTV video streams with highly demanding quality of service constraints and high reliability	Advanced Modular Systems (AMS) Sarnoff SGI	Yes	Integrated into the AgileVision system.
4	Distributed single-wire control and file transfer architecture to manage studio components under the direction of a master control workstation	Thales	Yes	Integrated in Thales digital transmitters; induced innovation in other transmitters.
5	Browser and query technologies to permit content-addressable retrieval of data	MCI	Yes	Network interface device developed and in service.
6	Digital adaptive predistortion (precorrection) technology used in the final transmission amplifier to accommodate FCC requirements for nonlinear power amplification of eight-vestigial sideband (8VSB) coded signals	IBM	No	Some technology transfer through consulting agreements.
7	Network interface to permit studios to be connected to external resources over wide area networks (WANs)	IBM Sarnoff Sun Microsystems	No	Sun: briefly had products available. IBM: some technology transfer through consulting agreements.

Source: NIST, 2001.

and later recompress signals to perform basic tasks and, therefore, mitigates equipment, bandwidth, and storage pressures in the studio. The server technology permitted compressed domain multicasting: real-time processing of transport feed of four SDTV channels or one HDTV channel.

The compressed bit stream switching and server technologies were commercialized in 1999 through a spin-off entity named AgileVision. AgileVision was operated jointly by Sarnoff and Mercury Computer Systems, a manufacturer of advanced parallel computing systems. It became clear that without explicit arrangements some JV technologies would not make their way to the marketplace. Thus, AgileVision was created as a commercializing entity and worked closely with Sarnoff during the last 2 years of the venture. Mercury Computer Systems was involved in AgileVision because the AgileVision system operated on Mercury's advanced high-performance parallel computer. AgileVision's system, the AGV-1000, has garnered several emerging technology awards since its release, including those from Broadcast Engineering and the National Association of Broadcasters (NAB). AgileVision was purchased by Leitch Corporation on February 8, 2002. AgileVision is no longer a stand-alone entity but has become one of Leitch's product lines.

The AGV-1000, billed as "DTV-in-a-box," has been well received by the Public Broadcasting Service (PBS) community. AgileVision is an economical choice for many PBS stations. The AgileVision unit allows them to buy a basic system for delivering a digital signal to customers for a few hundred thousand dollars rather than approximately $2 million. Most PBS stations apply for grants from the National Telecommunications and Information Administration (NTIA) for funding of such capital purchases. Thus, cost considerations factor prominently in their equipment investment decisions.

AgileVision is an integrated unit that runs with a high-performance computer. The PBS content distribution model calls for most PBS stations to pass through compressed streams of either four SDTV channels or one HDTV channel, depending on program schedules. The AgileVision system is well suited for this purpose, because it allows the stations to multicast signals while inserting select local content and logos. In this report, "AgileVision" is synonymous with the AGV-1000 and the JV technologies it embodies.

2.2.2 IBM

IBM was involved in two areas of JV research: file transfer architecture and video browsing and query. Though neither technology was commercialized through product offerings, IBM transferred knowledge through various consulting agreements with clients. In addition, IBM and, as will be discussed later in this section, Sun Microsystems indicated that the published results of uncommercialized research provided the DTV equipment industry as well as end users with constructs for approaching DTV conversion and digital studio organization.

Video Browsing and Query

IBM's Exploratory Computer Vision program investigated video browsing and query to permit content-addressable retrieval of data. The technology would allow the user to browse and query video content stored electronically on networked servers. The JV aimed to replace tape library systems in which technicians and editors search video-tape archives for footage during the creation of new content packages. The new system would be faster and more efficient.

When the JV was originally conceived, it was generally acknowledged that it would be helpful to have a media station where editors and technicians could browse through DV content. From a concept that originally lacked any formal definition, IBM's team developed a video database management system that allows users to semantically find pieces of footage. The system uses closed captioning, the audio track, and visual content to index data. However, working with visual information was exceedingly difficult. In addition, no equipment was readily available that could handle the large amounts of information needed to make such a system work.

By 1998, a state-of-the-art system had been designed for networked content management, but it was not commercialized because the system was not economically viable. IBM did consult with potential end users, imparting the knowledge gained through its R&D to a major cable network. It is also possible that a few pieces of the original technology developed under the JV were incorporated into other projects. IBM is currently revisiting plans for video content management tools and techniques.

File Transfer Architecture

A functional digital studio needs an advanced network for delivery of digital audio, video, and data. IBM investigated prospective applications of Asynchronous Transfer Mode (ATM) in the studio environment. ATM is a robust technology widely used by the telecommunications industry to deliver large amounts of data quickly. As a group, the JV became aware that working with compressed bit streams made control of these streams challenging. ATM offered the JV the opportunity to route large amounts of data quickly and efficiently through the studio. IBM was ultimately responsible for these routing and networking technologies, and Sun Microsystems was responsible for the command-and-control of the information as it was distributed throughout the studio.

After the initial three project years, the potential of collapsing all the ATM networking functions into a single computer became evident. With the addition of AgileVision, the need for the ATM networking within the studio declined. While ATM networking still holds potential application in large studios and distributed operations, the market pull for this aspect of the project declined significantly.

No technologies were ultimately directly commercialized. However, some technology transfer probably occurred through consulting agreements between IBM, an electronics manufacturer, and a major cable news network to develop an archival system.

The principal impact of IBM's effort in this area was on the future of networking and control design for digital studios. According to IBM representatives, although there was "very little explicit commercialization that emerged from the venture, from the point of view of influencing the community [the project] had a significant impact." Knowledge developed by the ATP project influenced other manufacturers, and when reviewing these manufacturers' products, according to IBM, kernels of JV research are apparent in their product designs, particularly in the realm of control. Manufacturers appearing to have been influenced by papers and conference proceedings include Leitch, Harris, and Miranda. In addition, several of the most salient points that appeared in an article describing a technical roadmap for how broadcasters would convert to digital broadcasting in the *SMPTE Journal* (SMPTE, 1998), the journal of the Society of Motion Picture and Television Engineers (SMPTE), were developed and investigated during the ATP project.

2.2.3 Sun Microsystems

Sun Microsystems developed a studio control technology based on information technology (IT) networking and an object-based approach. This technology was the protocol for controlling and routing digital video streams through the studio. Sun's strategy was to leverage the "plug-and-play" philosophy of the IT industry and create more interoperable and simplified studio control. Indeed, Sarnoff, IBM, and Sun attempted to drive the JV's "plug and play" approach to studio wiring through SMPTE's standards organizations, but point-to-point wiring was entrenched and the SMPTE audience ultimately proved to be unreceptive. It became apparent to Sun that the defender technologies were entrenched and that it would be difficult to gain standards status.

Sun commercialized the technology in its StorEdge Media Central product line, which was available for 2 to 3 years. The product achieved only limited success, partially because defender systems were entrenched and partially because Sun could not provide the resources to fully develop the infrastructure needed to support the product line in an era of economic uncertainty. The product was withdrawn from the market. A derivative product, Sun Media Appliance Platform, based on Java technology, was released in September 2002.

2.2.4 Thales Broadcast & Media[2]

To permit adjacent signal broadcasting, the FCC decreed extremely tight spectral shoulders for each new channel. Only with a very "clean" signal could broadcasters reliably use adjacent channels. Unfortunately, the power amplifiers used in high-power broadcast transmitters used non-linear amplification (for efficiency), which produces lots of unwanted energy in adjacent bands. The traditional approach for dealing with these unwanted signal components was to apply filters to the transmitter output. These filters, however, are very large and expensive, and significantly degrade the desired signal. With the exception of

[2]Comark Communications was the original name of this JV member. During the course of the JV, the entity's name changed from Comark Communications to Thomcast following a merger. The entity is now known as Thales Broadcast & Media.

Thales, all major broadcast transmitter manufacturers petitioned the FCC to relax the specification of spectral purity.

Thales's concept was to apply predistortion, sometimes referred to as precorrection, to prevent digital signals from bleeding over into adjacent bands, a technique that has been used successfully in analog broadcasting. Simply put, the technology anticipates out-of-band spectral products and injects signals equal in amplitude but 180 degrees out-of-phase into the broadcast stream before it reaches the amplifier. The technology automatically cancels out the out-of-phase signals, eliminating the distortion that would otherwise appear in adjacent channels. According to Thales, "Once the operator pushes a button, the problem takes care of itself." The technology is known as digital adaptive predistortion (DAP).

Thales believes DAP impacted the cost of the digital conversion for its customers, particularly during the 2 years in which its competitors had no equivalent products. DAP reduced the cost borne by broadcasters in meeting their digital transmission mandates. The first economic benefit was the price of the transmitter: Thales purchasers were able to buy 25 kilowatt (kW) transmitters for the same price it would have cost them to buy 20 kW transmitters from competitors (once filters had been installed). They obtained 20 percent more power for the original cost. The new technology reduced set-up time for transmitter installation by an engineer to 1 hour from 1.5 days. Finally, DAP allowed transmitters to more easily meet performance requirements while reducing the number of operations and maintenance hours. These benefits led to Thales receiving an Emmy Award for Technical Excellence from the Academy of Motion Picture Arts and Sciences in 2003.

2.2.5 MCI

MCI developed a digital interface technology that permitted the delivery of "theater-quality digital video over standard digital telecommunications facilities" (NIST, 2000). Individuals knowledgeable of MCI's JV-related research are no longer with the company; thus, it was not possible to interview the firm for this analysis. The company reported in a 2000 NIST project background piece that their digital transport service is "being used by a major cable TV programmer at 40 percent savings (saving tens of thousands of dollars monthly)" (NIST, 2000).

2.2.6 Other JV Participants

In addition to the organizations above, several other companies participated in the JV in some fashion, but their activity is not explored in depth in this analysis. For example, Philips Laboratories withdrew from the JV near the end of Year 3 when Philips made the business decision to move its research division from the United States to Europe. In all instances, the role each parting firm played was reallocated to another JV member or subcontractor.

2.3 HDTV JV PROJECT EFFECTIVENESS

JV members unanimously agree that the project was a productive and valuable experience. However, as is often the case with complex JVs, the HDTV project was at times affected by firms that left as their business strategies or circumstances changed. Understanding that each company's competency was required to make the project successful, new members and subcontractors were invited to join to compensate for competency losses. Still, the interpersonal and cross-collaborative relationships developed during the project were the key to its success, though the comings and goings of JV members caused some disruption.

Members indicated that the technologies they developed during the course of the JV would not have been developed in the absence of the JV and ATP funding, or if so, not as quickly. Without NIST ATP funding, Sarnoff doubts that JV members would have expended the resources to develop these technologies, let alone make the effort to perform the research jointly. The venture was able to generate significant synergy through facilitation of communication and knowledge exchange. Firms gathered quarterly at each other's facilities for meetings and to demonstrate technologies and share insights. This coordination was "invaluable."

The "DTV-in-a-box" technology developed by Sarnoff, and later commercialized by AgileVision, would not have been developed in the absence of the JV's project. In turn, the transition to DTV broadcasting would have been significantly more costly for PTV stations that adopted it, as will be discussed in Sections 3 and 4. Thales's introduction of a new transmitter embodying the DAP technology would not have occurred as quickly.

The JV most likely also improved DAP's quality and lowered its costs while accelerating its introduction. As another example, IBM might have been involved in this type of research, but the JV brought the firm into it sooner. The collaborative JV also developed IBM's knowledge much further than it would have been had it chosen not to participate or had the JV never existed. Similarly, Sun Microsystems stated that it collaborated with firms and technologies outside of its traditional business model, exposing it to new venues for its own R&D and potential market segments. Sun had been interested in exploring media asset control and management. When the JV presented itself as an opportunity, Sun welcomed it. The ATP funding multiplied Sun's resources and allowed the company to conduct research earlier than it would have in the JV's absence.

2.4 QUANTIFIABLE JV TECHNOLOGY OUTCOMES

Interviews with JV members suggest that the venture yielded positive technology outcomes in general, although each member individually met with varying levels of success. Sarnoff and its spin-off, AgileVision, as well as Thales each indicated that they were able to develop and successfully commercialize projects undertaken as part of the JV. The technologies embodied in their product offerings are a beneficial alternative to current and defender technologies. IBM and Sun Microsystems achieved technical success, yet market constraints usurped any potential viability for prospective products. Nonetheless, both firms reaped intellectual property benefits that may inform future technology investigations. The quantitative analysis will focus on the AgileVision system and Thales's development of DAP, while the benefits accruing to the efforts of other firms will be discussed among future directions in Section 5.

The first area of potential benefit to be analyzed is AgileVision's impact on the PBS member station market. Both Sarnoff and AgileVision indicated that AgileVision's AGV-1000 has both onetime and ongoing benefits for this market segment. The hypothesized onetime benefits consist of reduced equipment costs and faster installation turnaround. Ongoing benefits are hypothesized to stem from less labor required to operate the AgileVision unit compared to an alternative equipment installation.

Benefits associated with DAP are also analyzed. The interview with Thales indicated that the company's JV technology allowed them to introduce a digital transmitter that had cost, installation, and operations benefits over competitor products for two years. The transmitter more easily met FCC spectral requirements than did competitor products, allowing end users to reap routine maintenance benefits and avoid costly filtering. End users also avoided the need to purchase more powerful transmitters to compensate for losses associated with installing more powerful filtering technologies. Furthermore, other transmitter manufacturers invested in R&D to compete with Thales's technological innovation and introduced products to their customers sooner than would have occurred without the ATP JV project.

Among the suite of JV technologies developed, these two technologies have quantifiable economic benefits. Although qualitative benefits are associated with other JV members' technologies, there is no indication that those technologies are accruing any quantifiable benefits at this time or will in the near future.

3 Analysis Framework for Evaluating the HDTV Joint Venture Project

This section provides a framework with which the economic benefits of the joint venture (JV) project can be measured. The methodology approaches the project's technology outcomes from the counterfactual perspective of how digital television (DTV) broadcast operations would be configured had the project not occurred compared with the real-world scenario with the technologies. The incremental benefit that represents the difference between the two scenarios is the total benefit of the project.

The methodology consists of an economic analysis framework that presents the counterfactual to the JV, economic theory, the technical and economic metrics for quantifying benefits, and methodologies for collecting information needed to inform the analysis.

3.1 PUBLIC VERSUS PRIVATE BENEFITS AND COSTS

Before presenting the approach that underlies our evaluation of the high-definition television (HDTV) JV project, it is important to note that this analysis captures and evaluates both public and private benefits and costs. The concept of public versus private costs and benefits is best explained by answering the question of who pays for and who benefits from a technology's development.

Public costs are those costs borne by society for a technology's development; in this analysis, public costs would be the Advanced Technology Program's (ATP's) award to the JV for developing the technologies presented in Section 2. Private costs are those costs that are incurred by private entities. In this instance, private costs consist of the industry cost share; JV members provided 52 percent of the total JV budget.

To accurately compare total JV costs, both public and private, with benefits, it is necessary to collect public and private benefits. Public benefits are known as increases in consumer surplus: those benefits that accrue to society due to incremental price or cost reductions in products and services. As will be described later in this section, the JV economic analysis quantifies the cost savings JV technology adopters accrue relative to those for adopting alternative technologies. These cost savings are the JV's public benefits.

Private benefits are those incremental returns that accrue to the innovating firms, as a result of setting prices above their total average costs. Profit maximizing-companies will only be willing to innovate if they anticipate, ex ante, that they will be able to make a return that compensates them for expenditures on research and development and for acceptance of technical and economic risks. For innovating firms in highly competitive markets, however, their ex-post realization of profits may be small or even nonexistent. This is most likely if their rivals can quickly imitate their innovations and drive prices down to zero-profit, equilibrium levels. Available evidence strongly suggests that this result occurred for the two major products that emerged from the JV-developed technologies: digital adaptive precorrection (DAP) and the AgileVision system.

Total benefits of the project will be the sum of the incremental past and future benefits accruing to *consumers* from adopting JV-developed technologies (i.e., public benefits) and the past and expected future profits for *producers* (i.e., private benefits). Measures of economic return will compare the costs incurred to the combined public and private benefits created.

3.2 COUNTERFACTUAL SCENARIO TO THE HDTV JV PROJECT

To quantify the economic benefit of the HDTV JV project, the analysis will compare the *actual* situation of producers and users of project technologies to a *hypothetical* scenario in which the project did not exist. In the absence of the project's AgileVision and DAP, this analysis will argue that public television (PTV) licensees would adopt more costly studio installations and all DTV stations would use less efficient digital transmitters. This section develops the counterfactual world, describes the conditions that would arise, and presents evidence supporting the counterfactual. Specifying the counterfactual scenario is essential to determining the information that will be needed to estimate the public benefits of the JV.

Admittedly, the construction of a counterfactual scenario is a synthetic exercise; it is difficult or impossible to fully describe with a high degree of confidence a situation that does not exist. Nevertheless, with the large amount of data that we will collect and by using sound economic theory and logic, we can assemble a hypothetical scenario that should seem reasonable and credible to most observers. The use of counterfactual analysis, pioneered by Robert Fogel and once extensively debated, has become well accepted over the past 20 years (Fogel, 1979).

Section 2 identified two commercial products that had been introduced based on technology developed during the JV: AgileVision and digital transmitters with DAP. Because the analyses of these two innovations differ in both their scope and impacted populations, the counterfactual for each is presented separately. However, the same economic framework will be used for evaluating benefits.

3.2.1 Counterfactual to AgileVision

AgileVision embodies several of the JV's technology outcomes. In particular, the system integrates the JV's compressed processing, encoding, and file server innovations into one successful commercialization effort.[1] Sarnoff and Leitch provided comments on the system's application and market to accurately gauge AgileVision's impact. This information permitted the creation of a counterfactual against which the benefits of AgileVision may be compared.

[1] Sarnoff partnered with Mercury Computer Systems to commercialize these technologies in a spin-off venture originally named AgileVision. AgileVision existed as a stand-alone company for approximately two and a half years before it was purchased by Leitch. AgileVision is now the name of Leitch's product line that incorporates JV technologies.

AgileVision is hypothesized to have a significant impact on PTV stations' costs for converting their studio operations to digital broadcasting. As will be discussed at length in this section, PTV stations are the market for the AgileVision system because the system's capabilities match the Public Broadcasting Service's (PBS) content distribution model. By installing AgileVision, adopting stations avoid purchasing an array of studio equipment that would otherwise be needed to match AgileVision's capabilities. Furthermore, AgileVision permits stations to continue using existing equipment that would otherwise be replaced. The counterfactual to AgileVision therefore consists of a more costly alternative studio system implementation for DTV broadcasting.

AgileVision and the Public Television Market

AgileVision is an integrated DTV broadcasting solution housed in one piece of equipment that simplifies the delivery of either a four-channel standard definition (SDTV) feed or a one-channel HDTV feed. AgileVision is currently focused on the PTV member station market but intends to expand into the commercial station market in the future. The system is not viable in the commercial station market today because commercial stations originate a significant portion of their content. Commercial and some PTV studio operations require full-scale digital studio equipment implementations that permit sophisticated generation and manipulation of television signals. Examples of such content would be local news and entertainment programming. Since these studios invest in equipment that permits this more sophisticated content management and generation, it would not make sense to purchase AgileVision, a system designed to pass through network feed.

Apart from differences in content management and origination, three additional factors orient AgileVision to the PTV market:

1. PBS is motivated by its mission to promote education and disseminate information, whereas commercial stations are motivated by profit. These goals represent very different impetus and motivators. According to Leitch representatives, DTV is a boon to public broadcasters because it allows them to deliver multiple programming packages to targeted audiences in the community. AgileVision's four-channel SDTV output capability supports this.

Commercial stations have focused on HDTV. According to individuals interviewed for this analysis, most commercial stations believe that multichannel SDTV would fractionalize their audience, which would in turn have negative influences on revenue streams. Commercial stations "sell eyeballs to advertising" and HDTV concentrates the audience on one channel.

2. PBS member stations treated the May 1, 2003, digital conversion deadline very seriously and planned and invested to ensure they adhered as closely as possible to the deadline. The PBS network held conferences and maintains task forces to facilitate member stations' DTV rollout. AgileVision is a stand-alone tool that allows adopting PTV stations to install and begin operations quickly and inexpensively.

   Commercial stations, which had an earlier deadline, in large part opted to program and process signals in conventional analog technology and then encode their signals to digital for transmission. Because most commercial stations will be making extensive and expensive equipment purchases, they are focusing on digital technologies that deliver signals to homes rather than those that actually generate and edit the content in digital. When coupled with the fact that these stations will have to eventually purchase equipment that will make AgileVision redundant, it is more unlikely that commercial stations will adopt it under current conditions.

3. PBS uses a multiprogram transport stream to deliver content to member stations. That transport stream may be HDTV, four-channel SDTV, datacasting, or some combination thereof. PBS and AgileVision both employ the ATSC-standard, Moving Picture Experts Group, Version 2 (MPEG-2) compression 19.39 Mbps transport stream. Thus, AgileVision maps well with PBS's content distribution model.

   The major networks (ABC, CBS, NBC, etc.) have distributed a NTSC 45 Mbps transport stream to commercial stations via satellite for 25 years. This system was adopted as a replacement for shipment (via U.S. mail or Federal Express) of 2-inch video tape. Twenty-five years ago, the technical limit on compression was 45 Mbps, which corresponded to the satellite transponder bandwidth, as well as to the maximum capacity for the DSC-link. As such, industry adopted the 45 Mbps transport standard. This level of compression became known as "mezzanine-level" or distribution-level compression.

Given these technical considerations, AgileVision is marketed to PTV stations. As will later be discussed in Section 5, business drivers are emerging that will enhance AgileVision's viability for adoption in the commercial market. In addition, the AgileVision system is undergoing continuous redevelopment; the system's specifications may more closely align with the typical commercial station's studio operations in the future, though it is difficult to project the time such viability will be realized. This analysis therefore only quantifies the present, "first-generation" AgileVision system.

Alternative System Implementation to AgileVision

In the absence of the ATP project, JV members indicated that the JV would not have formed and AgileVision's enabling technologies, and therefore the system, would not have been developed. None of the project costs or benefits would have occurred. To quantify benefits, this analysis takes the approach of comparing the cost of installing AgileVision to the cost of installing some alternative system that would accomplish the same results.

AgileVision's core capabilities allow stations to provide some of their own content, pass through only a part of the PBS network feed, delay programs to another time slot, and/or add text and graphical content in addition to passing through PBS network content. AgileVision permits stations to adjust the Program and System Information Protocol (PSIP). PSIP supports on-screen programming information, program content timing, and channel designation. The channel designation capability is critical because without correct PSIP information, digital tuners cannot find the minor channel (e.g., channel 5.1 or 5.2) when a station is multicasting (delivering four channels of SDTV instead of one channel of HDTV). PSIP correction is a technical requirement for all stations because they may delay broadcast of some content or may need to adjust for their time zone or channel designation, for example. Stations can also brand their content by inserting logos and station identification spots and must provide a means to support (e.g., a message crawl) the emergency broadcasting system (EBS).

Leitch representatives note that to accomplish the above tasks without AgileVision, a station would need to

- decompress and decode the network feed to base band,
- route the feed to a master control switcher,
- insert logos and other information,

- re-encode and recompress the video, and
- route it to a PSIP corrector.

The station would need a router, a master control switcher, decoders and encoders, and process products (for inserting logos and EBS). If the station does not have these products, or if the products are not capable of handling DTV signals or if they are not interoperable, the station must purchase new ones. A plethora of products are needed; studios often build massive control rooms to add, drop, and insert content. Systems integrators (both consultants and engineers) are often called in to manage system design and set-up, charging large fees for their services. Additional employees would need to be hired to operate and maintain the digital equipment.

Information from South Dakota Public Broadcasting (SDPB) illustrates AgileVision's impact on studio configurations. The nine-station PTV network provided a detailed comparison of their prospective costs for converting their studio broadcasting operations to DTV with and without AgileVision that served as a major source of data for the analysis of benefits to pubic broadcasting stations nationwide. AgileVision lowered their equipment costs by $1.1 to $2.2 million (SDPB, 2003; see Table 3-1).

Table 3-1. Example AgileVision and Non-AgileVision Studio Conversion Cost and Equipment Comparison

Equipment Category	Conversion with AgileVision Cost Estimate	Alternative Conversion Cost Estimate 1	Alternative Conversion Cost Estimate 2
Encoding System w/ Logo Insertion	345,573	480,045	523,840
Studio Test & Monitoring	74,989	121,184	142,579
Satellite Downlink Equipment	15,000	36,683	36,683
Additional Studio Equipment	36,000	195,990	511,175
Video Server	—	500,000	950,000
Automation	44,400	266,650	358,450
Router	50,000	50,000	50,000
Master Control Switcher	—	69,028	189,084
Total	565,962	1,719,580	2,761,811

Source: South Dakota Public Broadcasting, 2003.

SDPB's cost savings were most concentrated in the areas of encoding equipment, studio automation, and video servers. Alternative Implementation 1 consisted of equipment purchases that would match the capabilities of a studio configured using AgileVision. Alternative Implementation 2 expanded those of Alternative Implementation 1 and added additional digital video servers and editing suites.

Hypothesized AgileVision User Benefits

AgileVision's user benefits lie totally within the studio. PTV viewers would notice no difference in the quality of the DTV programming they receive. Benefits are simply that PTV stations have less equipment to buy and need to allocate fewer labor resources to digital studio operations, management, and installation than they otherwise would have.

This study hypothesizes that there are three quantifiable economic benefits from using AgileVision: equipment cost savings, installation cost savings, and on-going labor savings. On the average, the AgileVision system costs $275,000. Comparable implementations may well cost $750,000 for an HDTV-only studio upgrade and $1.5 million for an HDTV/SDTV upgrade, as would be required to match the PBS distribution model. In addition to SDPB, several other PTV stations provided input on the costs savings of installing AgileVision. The mean response was used in the calculations. Simplified installation translates into lower one-time costs for "building-out" the DTV studio. In addition to capital cost savings, staffing requirements should be much lower with the AgileVision box. According to Leitch, one engineer can accomplish the work that would take several people using an alternative technology.

There are two additional benefits that are not quantified because they are more speculative and may not be true for all stations. These two benefits are maintenance agreement savings and electricity savings. It is possible that employing AgileVision reduces or eliminates fees for maintenance agreements for the alternative equipment. For instance, if a station opted for the alternative installation they may also opt for maintenance agreements for their equipment investment. An AgileVision adopter may also enter into such an agreement with Leitch.

However, it is unclear whether there would be a net benefit to the station of opting for the AgileVision agreement because PTV stations often do not sign on for maintenance agreements, according to stations interviewed for this analysis. Thus, we hypothesize that this benefit may exist for some stations, but it would be difficult to normalize this benefit across all stations because it is not known whether stations would enter into these agreements and what the increment may be, if any.

Additionally, there may also be electricity savings from running AgileVision as opposed to the alternative equipment installation. But respondents were not able to quantify this benefit and were unsure whether the benefit would exist since AgileVision operates similarly to a high performance computer and consumes a lot of electricity. The AgileVision benefit analysis will therefore yield a conservative estimate because of the inability to accurately gauge these additional two potential benefits.

Estimated Private AgileVision Benefits

The firm that commercialized the unique AgileVision technology would be expected to earn economic profits from sale of these units to customers over the life of the technology. As AgileVision was a single-product firm, the present discounted value of future expected profits would comprise a major share of the value of the enterprise. Leitch Corporation purchased this unique technology, and its future stream of sales and profits, when it bought AgileVision in February of 2002. An analysis of Leitch's Annual Report from that year indicates that the company purchased the AgileVision technologies for approximately 989,000 Canadian dollars, or about $619,000 (Leitch Corporation, 2002a).[2]

3.2.2 Counterfactual to Digital Adaptive Predistortion (DAP)

The counterfactual scenario to the development of DAP is similar to that for AgileVision in that DAP reaps equipment, installation, and operations and maintenance benefits for DTV stations. The technology enables more efficient digital transmitter operation because it provides a cost-effective means for mitigating television signal out-of-band products. Those products degrade the signal

[2]The 989,000 Canadian dollars was adjusted using the historical exchange rate for February 8, 2002, the day on which the AgileVision transaction was completed, as obtained from the Federal Reserve Board (FRB, 2003). The exchange rate on that date was 1.579 Canadian dollars to 1 U.S. dollar.

quality of channels in adjacent bands (Fries and Jenkins, 2000). DAP reduces filtering requirements and manual adjustments that would otherwise be needed to eliminate out-of-band products.

However, there is another dimension to the DAP counterfactual. Evidence exists that the results of the JV project's digital transmitter research reinforced the Federal Communications Commission's (FCC) spectral mask policy for adjacent channel signal broadcasting. Other transmitter manufacturers subsequently innovated and developed similar technologies that were introduced in the products they installed beginning in 2000. In DAP's absence, it is possible that the FCC might have relaxed its spectral mask policy at the request of a consortium of transmitter manufacturers. In that case, equivalent DAP technologies might not have been developed, or if so, might have been introduced at a much later date.

Postulating on potential counterfactual policy outcomes ex post is contentious. There is no chain of public reporting to support an argument that DAP was the sole catalyst for the FCC's restatement of its original spectral mask requirements. It is possible, however, to trace the chain of events surrounding the development of DAP and matching technologies from non-Thales manufacturers. This analysis assumes that the FCC would have maintained its spectral mask requirements regardless of DAP's development. It then estimates the costs that all DTV stations would have incurred to meet the spectral mask requirements in DAP's absence. In essence, the counterfactual scenario is that most DTV transmitters would have been more costly to purchase, install, and operate in the absence of the ATP project. The following discussion explores this scenario more fully and presents benefits and benefits population hypotheses.

Digital Transmitter Technological Innovation History, 1995 to 2000

The mechanics of digital transmitters are "not a big technological leap" (Jessell, 1996). Digital transmitters are a scaled-down version of analog transmitters with a digital exciter, the device that generates the broadcast signal. According to Jessell, "the principal difference is that digital transmitters have to be more linear—that is, less likely to generate spurious sideband signals that can interfere with adjacent channels" (Jessell, 1996). Herein lay the project's challenge; preventing digital broadcast signals from interfering with adjacent channels in an efficient manner necessitated innovative technologies that would maintain the linearity of the signal.

To effect the most efficient spectral planning, the FCC decided that it would be best during DTV conversion to initiate adjacent channel broadcasting and established spectral mask requirements to prevent any one signal from "bleeding" into an adjacent channel.[3] Preventing such interference posed a challenge for digital transmitter manufacturers (McConnell, 1995a): the FCC's spectral mask requirements were far more stringent than the broadcasting industry had experienced before (Fries and Jenkins, 2000).

Thales's DAP research beginning in late 1995 was focused on ensuring that DTV signals met FCC requirements. In the mid to late 1990s, other manufacturers focused their research efforts on developing advanced filtering technologies (McConnell, 1995b). In contrast, the JV developed technology for preempting out-of-band products that bypassed much of the need for stringent filtering. Though non-Thales manufacturers were able to develop digital filtering systems to meet FCC specifications, such filtering added to the total cost and reduced the operating efficiency of the transmitter (Jessell, 1996; Harris, 2002). The JV's development of DAP was successful and eliminated much of the additional filtering that would be required by other transmitter manufacturers.

Thales digital transmitters with DAP technology first entered into service in 1998; other manufacturers did not release transmitters with comparable technology until 1999 for service entry in approximately late 1999 or the beginning of 2000, though they already had digital transmitters in operation beginning in 1997.[4] The market for digital transmitters is highly competitive as one manufacturer's product is a close substitute for another's. Non-Thales transmitter manufacturers innovated and developed

[3]According to Fries and Jenkins, "[the FCC] desired to allow for adjacent channel allocations since the assignment of DTV channels was effectively doubling the amount of spectrum used by broadcasters. This required that some channels be assigned adjacent to other used channels with no guard intervals" (2000).

[4]According to individuals interviewed for this analysis, there was a 6- to 9-month time lag between the date a transmitter order was placed and when the transmitter entered into service.

technologies that met DAP's performance specifications. For example, in 1999, Harris Corporation, the leading transmitter manufacturer by total market share, introduced its Real-Time Adaptive Correction (RTAC) technology that provided continuous adaptive correction in the transmission system (Seccia and Simon, 1999). Other manufacturers soon followed suit. By 2001, nearly all transmitters delivered to DTV stations had some DAP-equivalent technology.

Given the level of competition in the broadcast equipment industry and the pattern of transmitter technological innovations, it is reasonable to assume that the JV's research demonstrated to other manufacturers an alternative to stringent digital filtering to prevent signals from bleeding into adjacent channels. Thus, this analysis proceeds on the premise that, in the absence of the ATP JV project, nearly all digital transmitters would be operating less efficiently. The hypothesized DAP benefits population consists of all DTV transmitters that contain DAP or equivalent technology. In essence, this includes all DTV transmitters except those from non-Thales manufacturers installed prior to 2000 that did not contain DAP.

Hypothesized DAP Benefits

Interviews with industry stakeholders suggested that there are three quantifiable benefits of DAP: equipment, installation, and operating cost benefits.

DAP reduces equipment and installation costs. Equipment cost-savings consist primarily of the savings associated with incorporating less filtering technology into the transmitter installation. Adaptive predistortion means that the transmitter automatically makes adjustments necessary to prevent most out-of-band products. In the absence of DAP, the installation specialist would manually adjust the transmitter's settings to meet performance specifications, which is more time consuming and therefore more costly.

There is also an ongoing operations and maintenance benefit in addition to onetime equipment and installation cost savings. A digital transmitter consists of several components: a DTV exciter (modulator), high-power amplifiers, band pass filter, combiners (if necessary), and test equipment (Luna, 2002). To simplify the discussion, these components are collectively referred to as the "transmitter." In actuality, the transmitter supervisor would be monitoring and adjusting the exciter and checking any adjustments using the test equipment. DAP's automation permits transmitter supervisors to perform less-frequent manual adjustments to the transmitter's settings.

Some stakeholders stated that the absence of significant filters permitted DTV stations to purchase transmitters of lower power level than they otherwise would have. The filters consume large amounts of electricity and therefore reduce operating efficiency. For example, a station might have to purchase a 25 kW unit as opposed to a 20 kW unit, thus incurring additional equipment expense.

However, the market for digital transmitters has shifted multiple times over the past 3 years. Some DTV stations purchased digital transmitters with geographical-coverage ratios equivalent to their analog transmitters while others have purchased very low-power ones. It is not possible to accurately characterize the distribution of transmitter output power, and consequently the distribution of equipment costs. Thus, this analysis only attempts to quantify the cost of additional filtering. Similarly, we were unable to quantify the cost savings of using less electricity through the operation of a lower power transmitter, though we hypothesize that such benefits do in fact exist.

Another area of potential benefit is the purchase of a backup digital transmitter. Broadcasters often had more than one analog transmitter because when a new transmitter was installed the transmitter it replaced was not discarded, but rather maintained as a back-up unit should the primary transmitter exit service. If the same was true for digital transmitters, then one would assume that at some point in the future, stations would purchase a second transmitter and reap double equipment and installation cost savings. This benefit is not quantified because it is unlikely stations would have more than one digital transmitter installed in the near future given the high capital cost of purchasing the first transmitter. The DAP analysis therefore yields a conservative estimate because the potential back-up transmitter purchase and electricity savings are not quantified.

Private benefits, in the form of producer profit, would be expected to accrue to Thales from this innovation, adding to the estimated economic benefits. However, there was a delay of several years between Thales' development of this improved technology and the increase in demand from television broadcast studios. It was not until the deadline imposed by the Federal Communications Commission's (FCC's) digital mandate approached that studios began purchasing significant numbers of digital transmitters. As a result of this delay, Thales' formidable competitors in the transmitter market were able to develop products of similar quality and performance, and their downward pressure on prices squeezed actual profits to a negligible level.

3.2.3 Summary of Technical and Economic Impact Metrics

Table 3-2 summarizes the technical and economic impact metrics presented earlier in this section. In addition, Table 3-2 also presents the metrics for evaluating investment costs incurred by the project, which are simply the sum of the ATP and cost-share funds expended to develop JV technologies. Since this analysis is measuring the performance of the JV project as a whole, including all studio technologies, total expenditures will be included, not just those for the development of DAP and the technologies embodied by AgileVision. As noted in Section 2, the JV would not have been successful had all members not contributed and commented on the program's direction and technology research and development.

3.3 METHODOLOGY FOR ESTIMATION OF ECONOMIC BENEFITS AND COSTS

This section discusses how economic benefits are created by the development of new technologies and describes a number of potential approaches to quantifying these benefits. The finalized approach presents a model similar to Mansfield's and explains how the model will be used to evaluate the success of the ATP HDTV JV project. This section concludes with a brief description of the primary metrics by which the economic benefits arising from the combined ATP and JV investment in the HDTV project are assessed.

Table 3-2. Summary of Technical and Economic Impact Metrics

Category	Technical Metric	Economic Metric
AgileVision Benefits		
Equipment Cost Benefit	Fewer pieces of studio equipment required.	Cost savings associated with purchasing AgileVision rather than an alternative system implementation.
Installation Cost Benefit	Simplified installation versus alternative system implementation.	Cost savings associated with installing AgileVision rather than an alternative system implementation.
Operations and Maintenance Benefit	Labor hours devoted to operating and maintaining alternative system implementation.	Relative labor cost savings of operating AgileVision rather than an alternative system implementation.
Private Benefit	Economic return to project participant	Estimated future profits from AgileVision product
DAP Benefits		
Equipment Cost Benefit	Less filtering equipment required.	Cost savings from avoided additional filtering technologies.
Installation Cost Benefit	Fewer labor hours required to install because of automated settings.	Relative labor cost savings of installing transmitters with DAP.
Operations and Maintenance Benefit	Labor hours associated with manually readjusting transmitter settings to meet performance specifications.	Relative labor cost savings associated with less frequent manual adjustments.
JV Project Costs		
Total JV Project Costs	JV research and development expenses, including labor and materials.	Sum of ATP and JV members expenditures.

3.3.1 Measuring the Benefits from Technological Change

Technological change generates economic benefits through the creation and use of entirely new goods and services, as well as through improvements in existing products. Truly novel goods increase the overall satisfaction of purchasers by delivering experiences previously unobtainable; by improving buyers' level of nutrition, comfort, security, or happiness; and by appealing to tastes for added variety. Improved products generate benefits by providing a given level of service at a lower opportunity cost to the consumer, by offering higher quality or performance level, or by delivering a broader array of services.

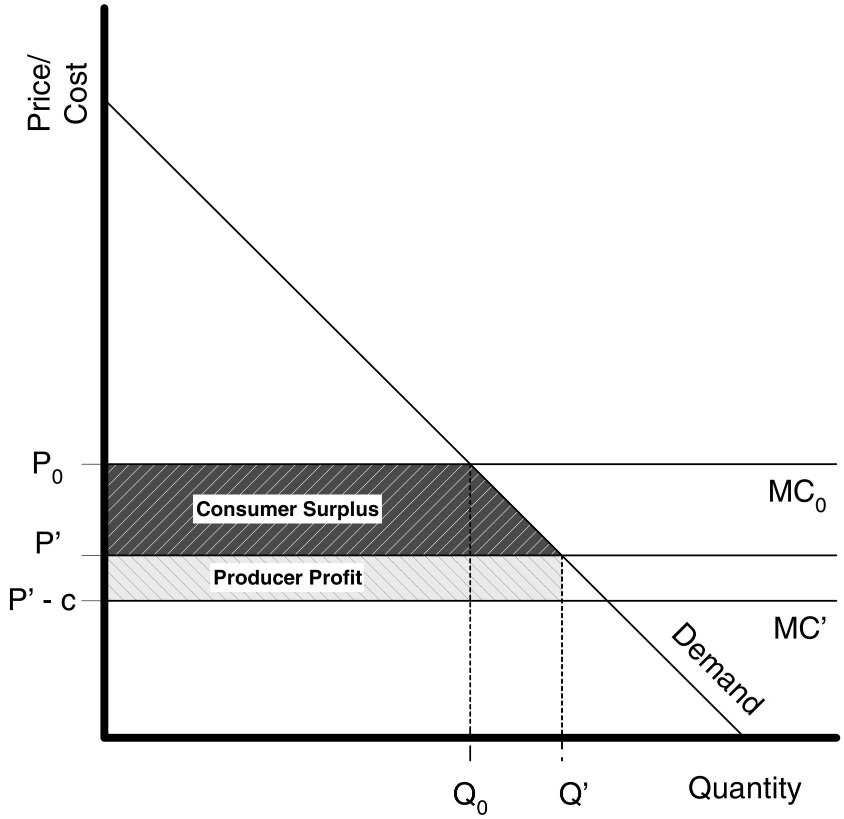
For example, the widespread adoption of television after World War II brought moving pictures into households for the first time; in that sense, it would be considered a new product. Television news improves timeliness over that provided by newspapers and conveys a greater emotional impact than radio news, both of which are quality improvements. As television makers have streamlined their manufacturing processes over the years, they have reduced prices charged to buyers for TV sets, an opportunity cost improvement. Finally, the addition of stereo sound and input devices has made it possible to play movies and video games on a piece of equipment formerly used only for displaying television broadcasts.

A variety of analytical methods can be used to measure these types of improvements, with the degree of complexity or sophistication depending on the difficulty of the measurement task. For new goods and improvements in multidimensional products and services, discrete choice models are often chosen (Berry, Levinsohn, and Pakes, 1995; Trajtenberg, 1989). If one or more dimensions of quality or performance are improved, price index (Austin and Macauley, 2000) or hedonic modeling approaches (White, 2000) are available.

When cost or price reduction to the user is the primary result of the improvement, a straightforward algebraic approach can be used, such as that described in Mansfield's classic paper on rates of return from industrial innovations (Mansfield et al., 1977). Figure 3-1 illustrates Mansfield's approach. An innovation affecting an input or production process lowers the user's marginal cost of production from MC_0 to MC'. The user can therefore cut its price accordingly from P_0 to P', and with downward-sloping demand, will increase output and sales from Q_0 to Q'.

The economic benefits from the innovation include all of the shaded areas in the figure. Reduction in the cost to the user from P_0 to P' creates a surplus for the customers of the good or service, which may in turn be passed on to the user's consumers in the form of lower product prices. If the innovating firm can set a price above its costs, it can earn a profit on each unit sold (c in the figure), realizing private benefits from its actions.

Figure 3-1. Mansfield's Approach for Evaluating Benefits of Technological Change



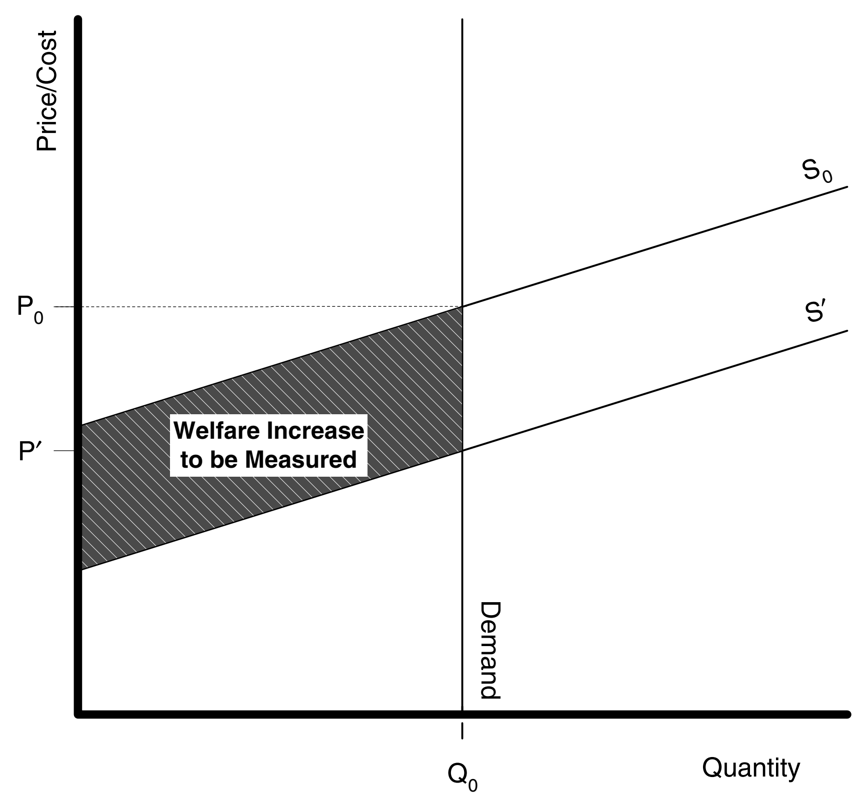
3.3.2 Approach to Measuring Benefits from the HDTV Joint Venture Project

In the current case study of ATP's HDTV JV project, both AgileVision and DAP created an almost pure cost impact on the broadcast studios that purchased them, just as in the firms that Mansfield studied in the 1970s. PTV stations faced with a mandate to convert their operations to digital format could choose one of two options—the more expensive defender installation, or the lower-cost AgileVision embodying JV-developed technology. Similarly, digital transmitters either included DAP or they did not. As explained in the previous section, counterfactual scenarios assess the hypothetical cost of choosing the defender option and compare it with AgileVision and DAP installations.

The nature of the FCC's digital mandate simplifies the analysis even further from that depicted in Figure 3-1. In conventional product and service markets, the innovation-induced price reduction will cause an increase in the quantity supplied in the final product market, either through expansion of the firm or market entry. In the case of the television studios, however, their quantity is fixed by access to operating licenses, and the FCC required them to install digital broadcast equipment. As a result, a reduced cost for digital equipment would not create market entry or induce firms to expand their operations.

Figure 3-2 illustrates the resulting model, with a slightly more realistic upward-sloping supply curve replacing Mansfield's assumption of constant marginal cost. The equilibrium with the defender studio technology shows the price on the supply curve at P_0 and quantity fixed at Q_0. Substitution of products containing the JV-developed technology allows a reduction in costs to the supply curve S', with price falling to P' in equilibrium.

Figure 3-2. Simplified Equilibrium Diagram of Digital Video Television Equipment Market



The social benefit from the innovation is represented by the shaded area between the supply curves, with quantity remaining constant. This can be shown algebraically to be equal to $(P_0 - P')$ Q_0. To operationalize this model, therefore, we need only estimate the change in supply cost for each station that will undergo conversion from analog to digital and multiply that per-station savings by the entire affected population.

Assuming that all stations have costs along the same supply curves is an oversimplification that requires additional discussion. Clearly, the operating costs of a broadcast studio are more complex than just those associated with the two technologies considered here. In addition, there is a considerable degree of heterogeneity within the broadcast studio community. As an example, commercial studios and large public TV stations that create much of their own content require a great deal of flexibility and capability in their equipment. They are likely to choose the more expensive defender technology, rather than AgileVision, to provide their operations with the equipment they need. For the cash-constrained PTV studios that receive most or all of their content in a compressed data feed, the AgileVision technology is optimal. For this reason, the value of Q_0 may be a subset of the population of studios, rather than the total quantity faced with the digital mandate.

3.3.3 Estimating Measures of Performance

The evaluation of the economic impact of the HDTV JV project involved calculating several performance measures, summed across the two principal commercialized applications, the AgileVision system and DAP. Total social benefits measured included public benefits arising from the cost savings achieved by the television studios, and private benefits from additions to innovator profits. Three measures—benefit-to-cost ratio (B/C), net present value (NPV), and internal rate of return (IRR)—provide estimates of the net social surplus created by the combined public and private investment. A more in-depth description of each of the measures follows.

Benefit to Cost Ratio (B/C)

Annual time series of benefits derived from the two products and program costs were assembled. Letting B_t be the benefits accrued in year t by technology users and JV members and C_t the total funding for the project in year t by ATP and industry, then the benefit-cost ratio for the program is given by

$$(B/C) = \frac{\sum_{i=0}^{n} \frac{B_{(t+i)}}{(1+r)^i}}{\sum_{i=0}^{n} \frac{C_{(t+i)}}{(1+r)^i}}, \tag{3.1}$$

where t is the first year in which benefits or costs occur, n is the number of years the benefits and/or costs occur, and r is the social rate of discount. In this study, r was set at 7 percent, the Office of Management and Budget (OMB) specified level. Because benefits and program costs may occur at different time periods, both are expressed in present-value terms before the ratio is calculated.

Net Present Value (NPV)

The NPV of the combined ATP and JV member investments in the HDTV JV project was calculated as

$$NPV = \sum_{i=0}^{n} \left[\frac{B_{(t+i)}}{(1+r)^i} - \frac{C_{t+i}}{(1+r)^i} \right], \tag{3.2}$$

where the terms have the same meanings as identified for the B/C determination. Any project that yields a positive NPV is considered to have been economically successful. Projects that show a positive NPV when analyzed using OMB's 7 percent real discount rate are socially advantageous. A negative NPV would indicate that the costs to society outweigh the benefits.

Internal Rate of Return (IRR)

The IRR is the value of r that sets NPV equal to 0 in Eq. (3.2). Its value can be compared to conventional real rates of return for comparable or alternate investments. Risk-free instruments such as government bonds can be expected to yield rates of return under 5 percent in real terms, while equities seldom return more than 10 percent over an extended period of time. In academic studies of the diffusion of new technologies, however, real rates of return of 100 percent or over have been found for significant advances with broad social benefits.

Because this study measures both public and private benefits generated by the JV, the IRR is equivalent to a rate of return to society from ATP's investment in HDTV technology. For this reason, the term 'social rate of return' is used throughout this report to describe the IRR.

3.3.4 Primary and Secondary Data Collection

Data to support this analysis were collected from both primary and secondary data sources. Primary data source encompassed JV members and DTV stations, which provided the majority of the data required to quantify the benefits and costs of AgileVision and DAP. These stations provided anecdotal, cost, and comparison information relevant to this analysis. To extrapolate station-level results, data on the number of digital PTV stations and the total number of DTV stations were obtained from the American Association of Public Television Stations and the FCC, among other sources. Data sources are more fully discussed along side impact calculations during the presentation of results in Section 4.

4 Economic Analysis Results and Measures of Performance

This section discusses the results of the economic analysis of AgileVision and digital adaptive predistortion (DAP) performed using the analysis framework outlined in Section 3. The economic analysis evaluates the Advanced Technology Program's (ATP's) high-definition television (HDTV) project's social (public plus private) economic benefit relative to its costs by employing the counterfactual scenario and quantifying technical and economic impact metrics.

The project is evaluated as a suite of technologies. As such, the total quantifiable social economic benefits from technology outcomes are compared with the combined ATP and industry project costs. The AgileVision and DAP analyses differ in terms of both their scope and impact categories; the benefits quantification for AgileVision and DAP are therefore discussed separately. Benefits from each analysis are combined and compared with the project's total cost using three measures of performance:

- Net Present Value (NPV);
- Benefit-to-cost ratio (B/C); and
- Social rate of return, more commonly called the Internal Rate of Return (IRR).

The analysis relies on primary and secondary data sources. Members of both the commercial and public broadcasting industry provided the data and comments used to calculate firm-level benefits. These results were then extrapolated using population data from secondary data sources. The sources that provide the information underlying the benefits calculations are presented in each section. The National Institute of Standards and Technology (NIST) provided the total HDTV project cost data.

This section presents

- the analysis and economic benefits of AgileVision,
- the analysis and economic benefits of DAP,
- time series of the joint venture (JV) benefits and costs, and
- measures of performance.

4.1 ECONOMIC BENEFITS ANALYSIS OF AGILEVISION

Public television (PTV) licensees that have adopted AgileVision have experienced onetime and ongoing economic benefits. For these licensees, AgileVision reduced up-front equipment and installation costs and offered operations and maintenance savings. This analysis explores these benefits in further detail.

A licensee may be either a one-transmitter PTV station, such as WCNY in Syracuse, New York, or a system with multiple stations and/or transmitters like UNC-TV, North Carolina's statewide PTV network with 12 transmitters.[1] It is important to note that PTV licensees with multiple stations and/or transmitters operate from a central broadcasting facility, known as a control point, and distribute their signal to their stations and transmitters using some means of transmission, most often microwave technology. AgileVision's benefits are concentrated in the digital studio installation at the operations center. Thus, this analysis quantifies benefits per licensee, not per transmitter or station, assuming that each licensee has one control point.

The AgileVision analysis first quantifies the economic benefit per licensee. Next, it estimates the number of adopters in the PTV licensee population and digital conversion time frame data. Many PTV licensees have yet to convert to digital television (DTV) broadcasting. It is challenging to project with great certainty how many potential adopters will actually adopt AgileVision. Given the great uncertainty, the total economic benefits are presented for

[1]Many of the "stations" in PTV systems are really high-power transmitter operations with their own four-letter call sign that allow the system's broadcasting center to distribute its signal over a larger geographic area or on multiple channels. However, this report adopts the Association of Public Television Station's practice of calling these transmitter locations "stations."

three scenarios of AgileVision penetration developed using AgileVision's known adoption history and comments from experts in the PTV community.

4.1.1 AgileVision Economic Benefit per Public Television Licensee

In performing this analysis, data were obtained from several current and scheduled AgileVision adopters, including Maine Public Broadcasting, South Dakota Public Broadcasting, WLVT, and WCNY. From their responses, this analysis estimated up-front equipment cost and installation benefits and ongoing operations and maintenance (O&M) savings. Table 4-1 summarizes these benefits, and details are provided below.

Table 4-1. AgileVision Adoption Benefit per Public Television Licensee (Control Point)

AgileVision Adoption Benefit, per Licensee (control point)	Dollar Value (2002$)	Occurrence
Equipment Benefit	1,290,000	Onetime
Installation Benefit	47,000	Onetime
Operations and Maintenance Benefit	58,000	Ongoing quarterly benefit

Source: RTI estimates.

Equipment Cost Benefit

As discussed in the analysis framework section, installing AgileVision replaces the need for several individual studio equipment components, including video file servers and compression and automation equipment. According to Maine Public Broadcasting Corporation's (MPBC's) Gil Maxwell, "AgileVision precludes having to build a new master control system and enables multiple channels, in either standard or high definition." Without AgileVision, MPBC would need to decompress the video feed from the Public Broadcasting Service (PBS), route to a new digital control system, recompress the output and "do that four times over because we have four standard definition (SD) programs. [In addition], we would have had to buy additional encoders (Leitch Corporation, 2002b)."

Adopting PTV licensees projected that the counterfactual equipment costs would range between $1.4 and $1.7 million. The typical AgileVision system implementation costs roughly $275,000, although that figure varies significantly depending on individual configuration options. On average, each licensee saved $1.29 million.

Installation Cost Benefit

AgileVision rolls the capabilities of several pieces of studio equipment into one box. Installation expenses are greatly reduced because each equipment component does not need to be installed individually, as would be required in an alternative studio installation. Furthermore, the additional cabling expense of connecting a larger number of equipment pieces is avoided.

The alternative to AgileVision has other costs as well. Systems integration consultants and engineers are often hired to assist broadcasters in implementing new studio configurations and to help ensure that each piece is compatible with the studio's new and existing equipment. According to one respondent, systems integration fees could total $50,000. In addition, if the current studio facility does not have sufficient space for new equipment, it may need to be renovated or expanded, which has adverse implications for budgets and productivity. AgileVision, on the other hand, fits neatly into existing rack space.

AgileVision's implementation involves its own installation costs, consisting of labor hours for employees and a fee charged by Leitch for on-site installation assistance and training. Internal labor expenses range from 24 to 48 effort hours and average 39 effort hours (AgileVision, 2001; respondents).

Based on installation cost data provided by respondents, this analysis estimates the installation benefit from using AgileVision to be $47,000, excluding any costs for studio renovation or expansion. The installation benefit is calculated by totaling estimated systems integration fees, internal labor charges, and cabling expenses and subtracting the labor charges and fees associated with installing AgileVision. To quantify labor charges, this analysis uses data from the Bureau of Labor Statistics' (BLS') Occupational Employment Statistics (OES). In this instance, the labor rate used was for an engineering manager in the broadcasting industry ($34.17 per hour) multiplied by 2 to include indirect labor expenses (BLS, 2002).[2]

Operations and Maintenance Cost Benefit

AgileVision is also expected to save adopters O&M labor expenses. The integrated, automated solution reduces the work load for broadcast engineers, particularly traffic managers, as well as for technical operations and maintenance staff. In many instances, the solution precluded the need to hire additional staff members to manage DTV broadcasting operations. This analysis estimates $58,000 in quarterly labor savings relative to the alternative system implementation.

The O&M labor benefit is calculated by estimating the cost of employment for avoided labor hour expenditures. Wage rates for broadcast technicians ($15.61 per hour) and technical maintenance managers ($13.98 per hour) for the broadcasting industry from the BLS OES were used to quantify the avoided direct labor expense (BLS, 2002). The resulting direct labor expenses were multiplied by 2 to capture indirect labor expenses.

4.1.2 Public Television Licensee Population and Digital Broadcasting Conversion Time Frame

In the United States and its protectorates, 179 PTV licensees operate 357 stations (Association of Public Television Stations [APTS], 2003). To determine AgileVision's potential market penetration, and therefore public economic benefits, we reviewed publicly available DTV conversion and AgileVision adoption information to identify current, scheduled, and potential AgileVision adopters. In addition, we identified PTV licensees that have converted to DTV broadcasting using the alternative system implementation.

PTV Licensee Population by AgileVision Adoption Status

Table 4-2 presents statistics from APTS coupled with current and scheduled AgileVision adoption data. For reference, scheduled AgileVision adopters are licensees that have committed to AgileVision but have yet to commence DTV broadcasting. In all, 10 licensees are known to have either installed AgileVision or plan

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[2]The most recent BLS OES wage rates are in 2001 dollars; they were, therefore, adjusted to 2002 dollars using national wage growth estimates provided by the BLS on its website.

Table 4-2. Current, Scheduled, and Potential AgileVision-Adopting Public Television Licensees and Stations as of February 7, 2003

	Licensees	Number of Stations	Converted Stations	Unconverted Stations
Current AV Adopters	3	11	8	3
Scheduled AV Adopters	7	17	—	17
All Adopters	10	28	8	20
Nonadopters	54	152	84	68
Potential Adopters	115	177	—	177
Total	179	357	92	265

Sources: Leitch Corporation, 2003; APTS, 2003; and RTI estimates.

to within the first 2 quarters of 2003.[3] Once all of these adopting licensees have completed their conversion, AgileVision will be used to operate 28 DTV stations, or 8 percent of all PTV stations.

Fifty-four licensees have converted or are converting to DTV broadcasting with an alternative system implementation. For this analysis, a licensee is considered a nonadopter when it converts at least one of its stations without AgileVision. This analysis assumes that the non-adopter licensee invested in an alternative system implementation for its control point. Though it is possible that a licensee may later upgrade to AgileVision after its original conversion, there is no way of predicting with certainty whether this would occur and, if so, how frequently. This analysis assumes that of the 179 total licensees, 115 have yet to convert and are therefore potential AgileVision adopters.

Estimating the PTV Conversion Time Frame

Information on PTV licensee digital conversion is available from PTV Digital, an online information service sponsored by the Corporation for Public Broadcasting (CPB) and TracMedia Services (PTV Digital, 2003a and 2003b). In some instances, licensees did not provide Digital Public Television (DPT) with specific on air dates. For those licensees, this analysis assumed that the known future adoption time frame was representative and

[3]As of February 7, 2003. Adoption information from AgileVision press releases as well as confirmed reports from PTV licensees.

mapped those licensees to an on-air date accordingly. Table 4-3 presents the estimated conversion time frame for all licensees.[4]

Potential AgileVision Market Penetration

Projecting the number of PTV licensees that will adopt AgileVision is problematic. The system is only now coming to the attention of broadcast engineers and it is reasonable to expect that a greater percentage of potential adopters will choose this technology.

If the uncommitted licensees choose AgileVision at the same rate as those who have already adopted AgileVision or are scheduled to adopt it, a total of 29 licensees will ultimately install the system. However, if the rate of adoption picks up, as is expected by most of our interviewees, as many as 75 licensees may choose AgileVision.

As a result, this analysis chose to estimate benefits over a range of total adopting licensees, from a lower bound of 29 to an upper bound of 75. A midpoint of 52 was also estimated. Potential future installations were projected proportionally along the conversion time series, with the results presented in the three right-most columns of Table 4-3.

Table 4-3. Estimated Conversion Time Frame for Public Television Licensees and AgileVision Market Penetration

Year of Conversion	All Licensees	Known AV Adopting Licensees	Potential Total Market Penetration		
			Low	Midpoint	High
1997	3	—	—	—	—
1998	3	—	—	—	—
1999	5	1	1	1	1
2000	13	—	—	—	—
2001	17	2	2	2	2
2002	13	—	—	—	—
2003	121	7	25	48	70
2004	4	—	1	1	2
Total	179	10	29	52	75

Sources: Leitch Corporation, 2003; APTS, 2003; and RTI estimates.

[4]Though this analysis presents results on an annual basis, the actual analysis calculated benefits on a quarterly basis to more accurately estimate total O&M benefits for both the AgileVision and DAP analyses.

4.1.3 Estimated Economic Benefit of AgileVision for Public Television Licensees

The total estimated adoption benefit of AgileVision ranges from $111 to $288 million through 2013 using the benefits per licensee and time trends for adoption. 2013 is a 10-year time horizon from the date of this analysis. A 10-year time horizon was selected because stations agreed that system will be in operation for at least 10 years, but were not able to hypothesize how many additional years beyond that horizon the system would be in use. Table 4-4 summarizes the total economic benefits to users for the range of AgileVision market penetration.

Table 4-4. Total Estimated Public Television Licensee AgileVision Adoption Benefit, through 2013

	Low Market Penetration (thousands of dollars)	Midpoint Market Penetration (thousands of dollars)	High Market Penetration (thousands of dollars)
Adopting Licensees	*29*	*52*	*75*
1999	1,400	1,400	1,400
2000	200	200	200
2001	2,000	2,000	2,000
2002	700	700	700
2003	38,800	74,100	107,900
2004	8,000	13,300	20,000
2005	6,700	12,000	17,300
2006	6,700	12,000	17,300
2007	6,700	12,000	17,300
2008	6,700	12,000	17,300
2009	6,700	12,000	17,300
2010	6,700	12,000	17,300
2011	6,700	12,000	17,300
2012	6,700	12,000	17,300
2013	6,700	12,000	17,300
Total	$111,400	$199,800	$287,900

Note: All benefit values are expressed in real, 2002 dollars. Sums may not add to totals due to rounding.

Source: RTI estimates.

The equipment and installation benefits were applied once to each licensee in the benefit population. O&M benefits were first applied in the actual or estimated quarter of adoption and then in each quarter thereafter.

4.2 ECONOMIC BENEFITS ANALYSIS OF DAP

Whereas the scope of the AgileVision analysis was limited to PTV licensees, the scope for the analysis of DAP is all DTV stations—both commercial and noncommercial. The DAP analysis is concerned with the total number of current and future digital transmitters. The analysis is similar to the AgileVision analysis in that it quantifies onetime and ongoing benefits for adopters. However, the definition of adopters is broader.

DAP adopters are those DTV stations that installed a Thales digital transmitter by the end of the second quarter of 2000 and all digital transmitters installed thereafter. As discussed in the analysis framework section, it is reasonable to assume that, beginning in the third quarter of 2000, all new DTV stations were broadcasting with digital transmitters that contain some type of DAP.

This DAP analysis quantifies the economic benefit of DAP per digital transmitter in the benefit population. Several DTV stations discussed the cost savings DAP has yielded for their operations. This analysis combines their comments with those from a transmitter manufacturer and industry data to calculate economic benefits. It is also important to note that this analysis assumes that each station has or will have only one digital transmitter.

4.2.1 DAP Economic Benefit per Digital Television Station

During interviews, digital transmitter stakeholders, which include DTV stations and manufacturers, said that DAP has both an equipment and installation cost benefit as well as ongoing O&M benefits. This analysis estimates the total onetime benefit to be about $30,700, including equipment and installation costs, and the quarterly O&M benefit to be $3,700 (see Table 4-5). The details behind these calculations are shown below.

Table 4-5. Per-Transmitter Benefit, Digital Adaptive Precorrection

Digital Adaptive Precorrection Benefit, per Transmitter	Dollar Value (2002$)	Occurrence
Digital Filtering Equipment Benefit	30,000	Onetime
Installation Benefit	700	Onetime
Operations & Maintenance Benefit	3,700	Ongoing quarterly benefit

Source: RTI estimates.

Equipment Cost Benefit

Filters are required to limit adjacent band interference in digital transmission. "Such filters are expensive, take up space, and drive up the cost of installation" (Jessell, 1996). DAP dramatically reduces, but may not eliminate, the need for output filters on digital transmitters. Digital filters[5] are used to mitigate out-of-band products; however, DAP preempts much of the need for filtering by inserting equal and opposite effects to counteract them. Transmitters with DAP may still require digital filtering technologies to prevent out-of-band effects. Stations and manufacturers interviewed indicate that, on average, the equipment cost benefit is $30,000 per transmitter.

Installation Cost Benefit

Transmitter installation and set-up, though still costly, has improved greatly over the years. Transmitters sit in facilities adjacent to TV towers and antennae, which are often located some distance from stations' studios. Anecdotal evidence and a review of broadcasting literature indicate that many stations have either retrofitted or expanded existing transmitter facilities; indeed, many have constructed new buildings.

However, stations would have incurred such costs regardless of their technology choice. DAP's benefit is in the time required to configure the transmitter's settings. Although it takes time with either system to ensure precise and accurate configuration, DAP reduced the effort required by more than 10 hours. This analysis estimates the installation benefit to be $700 per digital transmitter.

[5] The term "Digital Filters" used in this report is actually referring to the suite of analog filters required to condition the output of the analog amplifiers (either solid state or tube), which is the final stage of the "digital" transmitter. Digital television still transmits an analog signal, which is only modulated with digital information

The installation benefit is calculated by subtracting the with-DAP incremental set-up time from the without-DAP incremental set-up time. In this instance, the labor rate used was for an engineering manager in the broadcasting industry ($34.17 per hour) multiplied by 2 to include indirect labor expenses (BLS, 2002).

Operations and Maintenance Cost Benefit

DAP's O&M benefit consists of the labor hours transmitter supervisors would otherwise invest in correcting transmitter settings when out-of-band effects occur. In the absence of DAP, the transmitter supervisor would travel to the transmitter facility and manually adjust the transmitter's settings more frequently. This analysis estimates DAP's O&M benefits to be $3,700 quarterly.

The O&M labor benefit is calculated by multiplying the hourly benefit for transmitter supervisors (11 man hours) by the mean BLS wage rate for the most similar position, broadcast technician ($15.61 per hour; BLS, 2002). The resulting direct labor expenses were multiplied by 2 to capture indirect labor expenses.

4.2.2 Digital Television Station Population and Digital Broadcasting Conversion Time Frame

The conversion to DTV is by no means complete. As of January 30, 2003, 733 stations were broadcasting digital signals (NAB, 2003). However, there are 1,719 television stations in the United States (Federal Communications Commission [FCC], 2003a). Therefore, nearly 1,000 stations have yet to go on-air with a digital signal.

Secondary data sources were used to estimate the on-air time frames for DTV stations. Information on station digital conversion is available from 100000 Watts, an online information service that tracks developments in the broadcasting industry (100000watts.com, 2003). The service tracks FCC information and compiles the digital status of all television stations in the United States. In addition, Digital Tech Consulting compiled the on-air dates for existing DTV stations for the Consumer Electronics Association (CEA, 2003).

In some instances, specific on-air dates were not available from the referenced data sources for unconverted stations. For these stations, this analysis assumed that the rate of future conversion was similar to that of the past 2 years and mapped those stations to on-air dates accordingly. Table 4-6 presents the estimated conversion time frame for all stations.

Table 4-6. Estimated Digital Transmitter Benefit Population and Station Conversion Time Frame

Year of Conversion	All Stations	Benefit Population
1997	3	—
1998	45	9
1999	63	14
2000	58	31
2001	63	63
2002	381	381
2003	572	572
2004	534	534
Total	1,719	1,604

Sources: FCC, 2003a; 100000watts.com, 2003; and RTI estimates.

Table 4-6 also presents the DAP benefit population of 1,604 DTV stations. The difference between the total number of stations and the benefit population are those stations that installed non-Thales transmitters prior to the beginning of the third quarter of 2000. After that date, as described in Section 3, all stations were going on air with digital transmitters with DAP technology. Thus, to more accurately estimate benefits, non-Thales transmitters before that date must be subtracted from the total population to derive the benefit population.

4.2.3 Estimated Economic Benefit of DAP for Digital Television Stations

Using the per-transmitter savings and population figures from above, the total estimated economic benefit of DAP is $302 million through 2013 for the entire digital transmitter benefits population (Table 4-7). The same 10-year time horizon was applied for the DAP analysis as for the AgileVision analysis because respondents agreed that the equipment would be in operation for at least 10 years. The equipment and installation benefits were applied once to each licensee in the benefit population. O&M benefits were first applied in the actual or estimated quarter of adoption and then in each quarter thereafter.

Table 4-7. Total Estimated Economic Benefit, Digital Adaptive Precorrection, through 2013

Year	Digital Adaptive Precorrection Benefit (thousands of dollars)
1998	300
1999	700
2000	1,500
2001	3,300
2002	16,700
2003	29,900
2004	38,300
2005	23,500
2006	23,500
2007	23,500
2008	23,500
2009	23,500
2010	23,500
2011	23,500
2012	23,500
2013	23,500
Total	$302,500

Note: All benefit values are expressed in real, 2002 dollars. Sums may not add to totals due to rounding.

Source: RTI estimates.

4.3 TIME SERIES OF PROJECT COSTS

Sections 4.1 and 4.2 presented the analysis of benefits to users of HDTV project-developed technologies. This section presents the costs and creates a time series of costs for 1995 to 2000. The HDTV project cost $58 million, of which ATP provided $28 million (see Table 4-8). The balance of funds, $30 million, was provided by the JV members. The costs included direct and indirect labor expenses as well as equipment, travel, and materials costs (NIST, 2003; NIST, 1999).

Table 4-8. HDTV Project Costs, 1995–2000

Year	ATP Funding (thousands of dollars)	Non-ATP Cost Share (thousands of dollars)	Total in Nominal Dollars (thousands)	Total in Real 2002 Dollars (thousands)
1995	1,090	1,140	2,230	2,600
1996	7,390	7,810	15,200	17,500
1997	5,600	7,070	12,670	14,200
1998	6,640	6,030	12,670	13,900
1999	2,650	2,880	5,530	6,000
2000	5,000	5,210	10,210	10,600
Total	28,370	$30,140	$58,510	$64,800

Source: NIST, 2003; NIST, 1999.

The quantified benefits are analyzed in real terms using 2002 dollars; therefore, the project costs were adjusted to 2002 dollars, as well. The Bureau of Labor Statistics online inflation calculator, based on average Consumer Price Index (CPI) data, was used to make this adjustment for inflation (BLS, 2003). In 2002 dollars, the project cost $64.8 million.

4.4 MEASURES OF PERFORMANCE

In this section, the time series of Net Benefits is shown and three measures of the economic performance of the HDTV project are calculated: the net present value (NPV), the benefit-cost ratio, and the social rate of return. This section also breaks out benefits realized to-date from the total benefits estimate. Included in these calculations are the private benefits (profits) accruing to AgileVision, as well as the public benefits and the JV's private and public costs. It was discussed previously that, due to the competitive nature of the digital transmitter market, there are no significant private benefits attributed to Thales.

4.4.1 Time Series of Net Benefits and Measures of Economic Performance

Table 4-9 shows the time series of net benefits. The net benefits in each year are expressed as the sum of:

- DAP benefits,
- the AgileVision estimated range of benefits, and

Table 4-9. Time Series Net Benefits, 1995–2013

	Net Benefits		
Year	Low (thousands of dollars)	Midpoint (thousands of dollars)	High (thousands of dollars)
1995	–2,600	–2,600	–2,600
1996	–17,500	–17,500	–17,500
1997	–14,200	–14,200	–14,200
1998	–13,600	–13,600	–13,600
1999	–3,900	–3,900	–3,900
2000	–8,900	–8,900	–8,900
2001	5,200	5,300	5,300
2002	18,000	18,000	18,000
2003	68,800	104,100	137,800
2004	46,300	51,600	58,300
2005	30,200	35,500	40,800
2006	30,200	35,500	40,800
2007	30,200	35,500	40,800
2008	30,200	35,500	40,800
2009	30,200	35,500	40,800
2010	30,200	35,500	40,800
2011	30,200	35,500	40,800
2012	30,200	35,500	40,800
2013	30,200	35,500	40,800
Total	349,700	438,000	526,200
NPV of Net Benefits (1995 base year)[a]	126,400	165,900	205,200

Note: All net benefit amounts are expressed in real, 2002 dollars. Sums may not add to total due to rounding. A total of $619,000 in private benefits to Leitch Corp. are included in 2002 net benefits.

[a]To compute NPV, net benefits were discounted to 1995, using a 7 percent annual discount rate.

Source: RTI estimates.

- the private benefits of AgileVision, less
- ATP and JV-member expenditures.

The net benefits of the HDTV project are estimated to be between $350 and $526 million. As mentioned previously, net benefits are expressed as a range because AgileVision's benefits were calculated for a range of market penetrations.

JV members incurred project-related research and development costs from 1995 through 2000. Some positive benefits were accrued prior to the project's end because Thales released transmitters with DAP to the market after completing its research within the project's original 3-year time frame.

4.4.2 Realized and Total Net Benefits

Many of the benefits of AgileVision and DAP have been realized, meaning that they have accrued or will accrue to known current and scheduled adopters. Realized benefits are the sum of benefits from current and scheduled AgileVision adoptions and benefits from DTV stations currently on air with DAP.

Ten PTV licensees have or are committed to AgileVision. AgileVision's benefits considered "realized" are the sum of current and scheduled equipment and installation cost benefits, as well as past and future O&M benefits. Documented scheduled AgileVision installations are included in the realized benefits calculations because scheduled adopters have already made their purchase decisions. For example, if a licensee installed AgileVision in late 2001, they accrued equipment and installation cost benefits then, but also will accrue O&M benefits through 2013. This analysis assumes that the time series of O&M benefits for that station are realized even though they have yet to accrue in actuality.

Similarly, DAP's realized benefits are the equipment, installation, and O&M benefits that have accrued or will accrue to DTV stations that have purchased digital transmitters and are currently on air with DAP.

Table 4-10 separates realized from prospective benefits. Realized benefits total $169 million in 2002 dollars. After deducting investment costs of $65 million, the realized net benefits are $104 million. Using 1995 as the base year, the NPV of realized net benefits is only $23 million because current AgileVision adoption is low and many DTV stations have yet to go on air. When taking into account potential benefits, the NPV is estimated to be between $126 million and $205 million.

4.4.3 Measures of Performance

Three separate measures of the JV's performance are provided in Table 4-11. The estimated value of net benefits to the economy from the project exceeds the JV's investment costs for both the lower and upper bounds of our estimate. The NPV of net benefits

Table 4-10. Quantified JV Economic Benefits (Realized, Potential, and Total), Costs, and Net Benefits

	JV Benefits (thousands of dollars)			JV Costs (thousands of dollars)	Net Benefits (thousands of dollars)		
Realized							
Real (2002$)		168,700		64,800		103,900	
NPV (1995 base year)		74,600		51,300		23,400	
	Low	**Midpoint**	**High**				
Potential							
Real (2002$)	245,700	334,100	422,300				
NPV (1995 base year)	103,000	142,500	181,800				
	Low	**Midpoint**	**High**		**Low**	**Midpoint**	**High**
Total							
Real (2002$)	414,500	502,900	591,000		349,700	438,000	526,200
NPV (1995 base year)	177,700	217,100	256,400		126,400	165,900	205,200

Note: Realized benefits, costs, and net benefits include those benefits that have already accrued or will accrue to end users and the JV costs. Potential benefits are those estimated to accrue in the future for various levels of AgileVision market penetration. Net benefits are only shown for the realized and total and not potential scenarios as the JV costs are sunk and are not prospective. Note also that independent sums may not equal totals due to independent rounding.

Source: RTI estimates.

Table 4-11. Measures of Performance

	Bounds of Estimate		
	Low	**Midpoint**	**High**
NPV of Net Benefits (1995–2013) (thousands of dollars)[a]	126,400	165,900	205,200
Benefit-to-Cost Ratio	3.47	4.24	5.00
Social Rate of Return	24.9%	28.6%	31.7%

Note: All dollar values are expressed in real, 2002 dollars.

[a]To compute NPV, net benefits were discounted to 1995 using a 7 percent annual discount rate.

Source: RTI estimates.

is estimated to be between $126 million and $205 million. The benefit-to-cost ratio is between 3.47 and 5.00. The social rate of return is between 24.9 percent and 31.7 percent.

4.5 ECONOMIC ANALYSIS SUMMARY

Although the JV technologies' benefits do not directly accrue to over-the-air television audiences, the stations that employ either DAP or AgileVision have benefited. The nation's nonprofit public broadcasting infrastructure, particularly in areas with smaller populations and/or fewer financial resources has an alternative to a complete build-out of a brand new digital studio replete with expensive equipment and specially trained personnel. The AgileVision system allows adopting stations to save on equipment and labor costs while delivering the same level of service to its constituency. Likewise, DAP offers all DTV stations, public, and private to lower their equipment and O&M costs. Resources that may have otherwise been diverted to fund the purchase and operation of defender technology may now be available for enhancing broadcast operations in other respects and thereby improving the quality of service to audiences.

5 ATP HDTV JV Project Technologies: Looking Forward

In addition to examining the quantitative impacts of the Advanced Technology Program's (ATP's) high-definition television (HDTV) joint venture (JV) project, this analysis also compiled information about the future directions of JV-developed technologies. Not all project outcomes were commercialized, but nearly all have had some sort of impact on the future direction of research and development (R&D) in their respective functional areas. Indeed, even those technologies that were commercialized and quantified in this report are but first-generation iterations; these technologies are evolving and may be applicable in additional markets long-term. This section serves two purposes: to revisit and encapsulate the ATP-funded HDTV technologies in a broader context and to present known details on their future application.

5.1 MARKETS BEYOND DTV BROADCASTING

This study includes an evaluation of HDTV project technologies' potential for markets beyond digital television (DTV) broadcasting, especially corporate communications and satellite and cable television providers. In general, JV members thought that the market scope for these technologies was limited to the terrestrial television broadcasting industry. Sarnoff noted that most cable providers mainly distribute analog signals over digital networks. Satellite is broadcasting digital signals, but the equipment was up and running before the ATP project started. Some HDTV-project technologies, particularly IBM's and Sun's research, would be applicable in any market where routing and query of video data was needed.

The technologies with the most realistic set of future benefits are those commercialized through AgileVision. Earlier sections of this report described the impact the AgileVision system has had and will have on the costs of DTV broadcasting for public television (PTV) stations. Indeed, in terms of relative value, the Public Broadcasting Service (PBS) member stations, and therefore their constituencies, may be the single-largest beneficiary of the ATP-funded HDTV project. Looking forward, AgileVision has two other prospective areas of benefit: commercial television broadcasting and datacasting.

5.1.1 AgileVision and Commercial Television Broadcasting

AgileVision's multicasting capability, in other words its ability to simultaneously broadcast more than one channel using the same amount of allotted spectrum, and commercial television broadcaster's search for new revenue sources may increase AgileVision's viability in the commercial television station market. Heretofore, commercial broadcasters were opposed to multicasting on their allotted DTV signal because it would fractionalize their audience, meaning that fewer people would be watching their one channel. This would in turn have adverse implications for advertising revenues. However, a business case is developing for conditional access (pay-to-view) television in over-the-air broadcasting.

Cable system operators often sell an additional tier of cable television service called "digital cable" that delivers a larger number of channels to consumers for an additional fee per customer per month. Over-the-air broadcasters are beginning to see the business case for providing similar services to viewers using their DTV signal allotment. AgileVision's multicasting capabilities are, therefore, attractive as broadcasters could deliver free content on a portion of the signal and then provide conditional access channels on the remaining portion of their signal.

5.1.2 AgileVision and Datacasting

Datacasting refers to the broadcast of data streams by a DTV transmitter. The phrase comes from the combination of data and broadcasting. Datacasting is the process of taking computer data stored in large files, packaging them, and sending them over the air to the public at large or subscribers (WHYY, 2003).

According to Idaho Public Television, “Television tuner cards can be plugged into a computer, a set-top box attached to an analog TV, or a DTV set to capture the digital signal. Once received, the equipment will separate the data bits from the television programming bits and either display the data on screen or save it to a hard drive for later use” (2003). Datacasting service complements the services provided by Internet-service providers.

In addition to serving homes and businesses, DTV stations may also devise methods for delivery of data to educational institutions, public services, and hospitals, among other potential end-users hypothesized by stations interviewed for this analysis. Public DTV stations may also form for-profit subsidiaries to datacast everything from stock quotes to games to local businesses and residences. PBS has formed such a subsidiary called PBS National Datacast and plans a variety of either subscription-based or advertising-supported services (PBS, 2003). Datacasting offers digital PTV stations the opportunity of additional revenue sources.

Several datacasting initiatives are currently underway. For example, WHYY in Philadelphia offers educational datacasts through partnerships with local education authorities, including those for early childhood education, workforce development, and higher education (WHYY, 2003).

Datacasting is an enormous opportunity for over-the-air broadcasters because they can supplement their revenues by leasing spectrum for delivery of data to consumers. AgileVision itself is not a datacasting tool, but it provides a platform from which datacasting can be accomplished. AgileVision is designed to complement especially-designed datacasting servers and other equipment. Adopting broadcasters can integrate supplemental datacasting equipment with the system and commence operations. One of the stations interviewed indicated that AgileVision will lower future datacasting equipment costs but could not enumerate an estimate.

Although the JV did not investigate datacasting specifically[1], the commercial embodiment of several of its technical objectives provides a datacasting platform. As AgileVision would not have otherwise existed, the future benefits of datacasting through AgileVision can be attributed to the JV as well.

5.2 QUALITATIVE REVIEW OF THE HDTV JV PROJECT

A significant outcome of the project is that the knowledge generated during its course, evident in conference proceedings, journal articles, and patents, had an impact on the way R&D entities approached digital studio equipment and the theory underlying how such a studio should be organized (see Section 2.2). During and after the project, members prepared reports and articles for the technical literature as well as participated in standards-setting organizations and conferences devoted to television broadcasting. JV members contacted for this study mentioned anecdotally the comments they have received from their peers about the quality of their research and its relevance to contemporary DTV challenges. Indeed, JV members pointed to product offerings from nonmembers, technical roadmap articles, and other evidence that included kernels of their research.

This knowledge likely would not have been generated had it not been for ATP's involvement. JV members unanimously agree that the JV would not have formed and the project would not have occurred in the absence of ATP involvement. ATP's funding support permitted JV project participants to embark on research activities that would otherwise not have occurred or would have occurred at some unknown point well into the future. In essence, members credit the program for making the R&D outcomes possible.

The JV set for itself seven technical goals, all of which were successful, though only five of the accomplishments have been incorporated into commercial products. Those that have not found full-scale commercial outlets still have had an impact. IBM and

[1] Datacasting was not in the technical scope of the HDTV project, however, a datacasting demonstration was undertaken at WNJN, Trenton, NJ that used the project's prototype equipment in conjunction with third-party datacasting equipment.

Sun both indicated that their R&D efforts are molding approaches to new product development efforts.

It is likely that the project will have additional benefits that have yet to occur. Those benefits would come in the form of new product offerings with capabilities greater than and/or costs less than existing or future technologies. Those product offerings may be from a JV member (e.g., IBM or Sun Microsystems), or a non-JV member that applied the concepts employed in the JV and/or the published results of IBM and Sun's research in its own efforts.

An example of such an occurrence was documented in this analysis during the discussion of DAP in Sections 2 and 3. Thales's DAP research induced innovation in the digital transmitter industry. Other manufacturers matched Thales's technology with derivatives of their own, and thereby the entire digital transmitter industry benefited from JV research.

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