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

Draft Final Report

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*RTI International is a trade name of Research Triangle Institute.

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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 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's
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

Technological progress is the key to offering future populations the potential for improved standards of living. Technical change enables firms to combine inputs in a novel manner to produce existing products more cheaply and to develop new products to meet consumer needs. Economists and other social scientists are in broad agreement that technological change is the most important contributor to economic growth in the modern era. Based on Robert Solow's and Moses Abramovitz's path-breaking work more than 40 years ago, economists have estimated that more than half of our country's long-run growth is attributable to technological change (Solow, 1957; Abramovitz, 1956).

Whenever an individual or a firm makes a technological advancement that improves the performance or quality of a product or reduces the cost of making it, the overall level of social welfare in the economy is increased. Likewise, when a new product or service is developed, welfare is increased 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 welfare increase "spills over" to consumers or to other economic agents (Mansfield et al., 1977; Scherer, 1999), because the innovating firm typically cannot extract all of the surplus created. If there is sufficient rivalry among producers, for example, prices may be driven down to the point that the innovating firm cannot retain any surplus and thus is unable to recover 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 economists call "knowledge spillovers."

This investment recovery risk to innovators lies behind our nation's patent and copyright protection systems. The promise of a limited monopoly offers firms and individuals assurance that they will be able to retain some of the surplus from their creations. If this intellectual property protection is sufficient to induce firms and individuals to pursue all socially beneficial innovations, private levels of investment will be optimal. Even if some improvements are not made because of the existence of spillovers, the losses from these marginal innovations may not be large enough to justify an extensive government role in product and process development.

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 suboptimal 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 underinvestment by private firms. ATP funds, on a cost-sharing basis, precommercial research and development into new technologies and process improvements where substantial spillovers are expected and where technical and investment recovery risks are high. For example, ATP plays a role in providing funding for small firms that may not have access to other sources of capital due to lenders' risk evaluation processes. Banks and venture capital firms, which are primarily concerned with the private return on their investment rather than improvements in social welfare, often are unwilling or unable to properly evaluate the risks and potential returns involved.

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;
- third-party 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.

The economic methodologies and tools used by the external assessors have varied widely in these case studies, depending on the types of activities funded, outcomes of the public investment involved, and EAO's evaluation needs. For example, for projects yielding process improvements that raised finished product quality at a somewhat higher unit cost, a macroeconomic analysis would capture the net social benefits. Such an approach was used in two studies in the automotive sector (CONSAD, 1997; Ehlen, 1999). Mansfield et al. (1977) pioneered methods that evaluated the effects of new products and/or processes in reducing downstream production costs. Price-index concepts for measuring the value of performance improvements have been applied in a recent study of digital data storage technologies (Austin and Macauley, 2000).

1.3 RTI'S APPROACH TO EVALUATING THE HDTV JOINT VENTURE

The 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 non-profit broadcasting equipment R&D firm, assembled a unique team and led that team to an ATP award to investigate new approaches to creating and operating digital studios.

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 concentrating 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 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 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.

To quantify the economic benefit of the JV, 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. Once the counterfactual is specified and data collected, this analysis employs economic theory and quantifies the JV's benefits.

1.4 ORGANIZATION OF THE REPORT

This report discusses the technology outcomes of the JV, describes how JV technologies impacted digital television 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 research and development of a constituent component of the hypothesized digital television 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 its counterfactual scenario.

Section 4 presents the results of the quantitative analysis and calculates measures of economic return. 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 economic return, including the benefit-to-cost ratio, social rate of return, and net 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 research and development activities of the broadcast equipment industry and the digital television conversion. The report also concludes by looking forward to the potential benefits JV technologies may yield in the future.

2 Overview of the HDTV Joint Venture and Technology Outcomes

The 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 non-profit broadcasting equipment research and development (R&D) firm, assembled a unique team to investigate new approaches to creating and operating digital studios and received funds from the National Institute of Standards and Technology's (NIST's) Advanced Technology Program (ATP). This section provides an overview of the JV, 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.

2.1 THE HDTV JOINT VENTURE

The Federal Communications Commission (FCC) mandated conversion to DTV broadcasting requires studios at U.S. television stations to convert their operations from analog to digital systems. 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.

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 for parallel operations in both analog and digital through mid-2006. While making these changes, broadcasters must maintain their on-air analog and digital operations, which places financial pressures on all stations' operating and facilities budgets. The situation was further complicated by the fact that as the DTV conversion commenced, digital equipment had yet to achieve satisfactory performance specifications.

In the 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

The nation's looming DTV broadcasting conversion catalyzed R&D efforts in making such a transition feasible and economically viable. From the public technology policy perspective, NIST's ATP was uniquely positioned to organize and support R&D efforts; one of ATP's goals was to fund high-risk, high-reward ventures in the realm of digital video (DV) technologies that could potentially yield social and economic benefits and ease and reduce the risks inherent in the shift from analog to DTV broadcasting. ATP has funded eight projects through its focus program, "Digital Video in Information Networks" (ATP, 2003).

In explaining NIST's involvement, program manager David Hermreck said the institute funds "technology ideas considered too risky or too long-term to pursue by private companies alone, but recognized as bringing potential benefit to the U.S. economy" (Yoshida, 1998). 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 unbiased, 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 could otherwise have been underfunded, and therefore economically unviable.

2.1.2 JV Research and Development Goals

The JV's goal was to develop and commercialize a comprehensive suite of technologies to enable efficient HDTV studio operations. At the time the JV was conceived, DTV stakeholders were concentrating on adopting a digital television 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. 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 was very expensive in the early 1990s and therefore was a significant roadblock to DTV conversion. Therefore, the JV's mission was to develop technologies that permitted studios to work with compressed feed.

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 feed distributed by television networks. The JV envisioned a new breed of broadcasting studio and set for itself a series of technical objectives:

innovative technologies that would permit processing, distribution, control, data management, and broadcasting 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 Studio Component Objectives

Encoding and transcoding technology to manipulate the highly compressed HDTV pictures that will be used in the studio
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 mange studio components under the direction of a master control workstation
Browser and query technologies to permit content-addressable retrieval of data
Digital adaptive predistortion technology prior to transmission to accommodate the sensitivities to 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.

It is important to note that the scope of DTV broadcasting has broadened beyond HDTV to include standard-definition television (SDTV), DTV whose quality matches or slightly exceeds that of today's analog broadcast television. Throughout this report, DTV includes both HDTV and SDTV.

2.1.3 Organization and Mechanics of the HDTV JV

The JV led by the Sarnoff Corporation ran from late 1995 through 2000. Though the JV was originally scheduled to run 3 years, the project was extended an additional 2 years to adjust technical objectives to market changes and to accommodate trials of technology outcomes (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 to join. The addition of 2 years allowed the JV to refine its technologies in reaction to emerging market conditions.

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 with its studio constituents. The JV leveraged the individual competencies of each member to create a whole greater than the sum of its parts.

The original JV group comprised nine firms, which were awarded $28.4 million in ATP funding (see Table 2-2). An additional firm, Thomson Electronics, was technically a member, but contracted its R&D to Sarnoff. National Broadcasting Company (NBC), a major broadcasting network, was a noncost contributing member providing technical and operations experience. Additional firms were invited to fill gaps in technical competency as nonmembers through subcontracts with Sarnoff.

The total estimated JV budget was $58.6 million, at 48 percent cost share with industry. ATP provides funding on a cost share basis, meaning that the program requires award recipients to infuse their own financial resources in the project. In this instance, JV members provided 52 percent of the JV's total funding and ATP provided the remaining funds. At the JV's completion, $58.5 million was spent to develop new technologies for digital studio operations, a figure slightly less than the JV's original budget estimate.

2.2 JV TECHNOLOGY OUTCOMES

Both NIST and the group of JV members have prepared several reports and papers that present the technical detail of the technologies that emerged from the venture.[1] This section therefore does not summarize the technologies' technical characteristics. Rather, it presents and analyzes member comments and identifies social and economic benefits.

2.2.1 Sarnoff Corporation

Although Sarnoff codeveloped several technologies with other JV members, Sarnoff's 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.)

[1]See National Institute for Standards & Technology (NIST). 2001. "HDTV Broadcast Technology Post-Project Report." July 27, 2001. Cooperative Agreement Number: 70NANB5H1174. Gaithersburg, MD: National Institute for Standards & Technology.

Table 2-2. JV Members, Estimated Funding, and Participation

Firm	ATP Funding	Cost-Share	Total Estimated Funding[a]	Years of Participation	Participation Status
Sarnoff Corporation	16,000,761	13,150,803	29,151,564	1995–2000	JV Leader
Thales Broadcast & Media[b]	1,614,327	2,473,662	4,087,989	1995–2000	JV Member
IBM	3,842,337	4,696,190	8,538,527	1995–2000	JV Member
Thomson Electronics	—	—	—	1995–2000	JV Member; Contracted research through Sarnoff
Sun Microsystems	671,065	820,191	1,491,256	1995–1998	JV Member
NBC	—	—	—	1995–1998	JV Member
WorldCom	887,951	1,085,274	1,973,225	1995–1998	JV Member
Philips Electronics	2,241,376	2,739,460	4,980,836	1995–1999	JV Member
Advanced Modular Systems (AMS)	3,163,606	4,278,287	7,441,893	1995–1997	JV Member
New Jersey Network (NJN)	—	960,512	960,512	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
Total	**28,421,423**	**30,204,379**	**58,625,802**		

[a]Total Estimated funding does not match actual funding due to changes in research objectives and JV participation from 1995 through 2000.

[b]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, 1999.

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 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 Sarnoff's spin-off entity named AgileVision. 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. 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 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. Most PBS stations write grants to the National Telecommunications and Information Administration (NTIA) for funding of capital purchases. 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 dollars.

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.

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. The JV aimed to replace tape library systems in which technicians and editors search 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.

Though by 1998, a state-of-the-art system had been conceived for networked content management, 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 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 Asynchronous Transfer Mode (ATM), a cell structure for delivering information infrastructures for the JV. As a group, the JV became aware that working with compressed bit streams made control of these streams challenging. IBM was ultimately responsible for routing and networking technologies and Sun Microsystems was responsible for the command-and-control issues.

Ultimately, no technologies were 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 JV] had a significant impact." Knowledge from the JV 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 of a recent article describing a technical roadmap for how broadcasters would convert to digital broadcasting in the *SMPTE Journal* (SMPTE, 1998) were identified as part of the NIST ATP program.

2.2.3 Sun Microsystems

Sun Microsystems developed a studio control technology based on information technology (IT) networking and an object-based approach. 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 this technology through the Society of Motion Pictures and Television Engineers' (SMPTE) standards organizations, but point-to-point wiring was very predominant 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]

The FCC plans to roll out digital television called for allotting television stations new spectrum on which to broadcast digital signals. However, as the analog spectrum would not be available until the digital conversion was complete, there was a need to conserve spectrum by assigning every channel, rather than leaving adjacent channels empty as had been done with analog broadcasting. This would require digital signals to

[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.

essentially occupy a narrower spectral bandwidth, without the out-of-band products that bleed over into adjacent channels. Such products are detrimental to the quality of the impacted signal. Existing filtering technologies were not capable of preventing signals from bleeding over; Thales's role in the JV was to develop a technology that would allow adjacent channel transmission for digital terrestrial broadcasting.

Thales's concept was to apply pre-distortion correction to the issue, a technique that has been used successfully in analog broadcasting. Simply put, the technology anticipates out-of-band 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 precorrection (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 got 20 percent more power for the same cost. During transmitter installation the new technology reduced set-up type by an engineer to one hour from 1.5 days. Finally, DAP allowed transmitters to more easily meet performance requirements while reducing the number of operations and maintenance hours.

2.2.5 WorldCom

WorldCom developed a digital interface technology that permitted the delivery of "theater-quality digital video over standard digital telecommunications facilities" (NIST, 2000). However, individuals knowledgeable of WorldCom's JV-related research are no longer with the company; it was not possible to interview the firm for this analysis. However, as reported by the company in a 2000 press release, 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 are 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 JV EFFECTIVENESS

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

Members indicated that the technologies they developed during its course 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 perform the research together. 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, which was "invaluable."

The "DTV-in-a-box" technology developed by Sarnoff, later commercialized by AgileVision, would not have been developed in the absence of the JV. Thus, in turn, the transition to digital television broadcasting would have been significantly more costly for adopting PBS stations, as will be discussed in Sections 3 and 4. Thales's introduction of a new transmitter embodying the DAP technology would not have been developed as quickly. The JV most likely also improved the technology's quality and lowered its costs in addition to accelerating its introduction.

IBM, for example, 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 far more than it would have been had it chosen not to participate or had the JV never existed. Similarly, Sun Microsystems stated that it worked with firms and technologies outside of its traditional business model, exposing it to new possibilities and market segments. Sun had been interested in exploring media asset control and management, and 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/AgileVision and 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. However, both firms reaped intellectual property benefits that may inform future technology investigations. The quantitative analysis will therefore focus on the AgileVision system and Thales's development of DAP, while the benefits accruing to the efforts of other firms will be discussed 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 one-time and on-going benefits for this market segment. The hypothesized one-time 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.

Potential benefits associated with DAP will also be analyzed. The interview with Thales indicated that the company's JV technology allowed Thales to introduce a digital transmitter that had cost, installation, and operations benefits over competitor products for 2 to 3 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. Thus, the Thales transmitters were more cost-effective. Furthermore, other transmitter manufacturers invested in research and development to match Thales's technological innovation.

Among the suite of JV technologies, 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 be in the near future.

3 Analysis Framework for Evaluating the HDTV Joint Venture

This section reorients the background information detailed earlier in this report toward an economic analysis framework with which the economic benefits of the JV can be measured. The methodology that will be described herein approaches the JV's technology outcomes from the perspective of how DTV broadcast operations would be configured had the JV not occurred. It then compares that counterfactual with the real-world scenario with the JV technologies. The incremental benefit between the two scenarios would be the total benefit of the JV.

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 COUNTERFACTUAL SCENARIO TO THE HDTV JV

To quantify the economic benefit of the HDTV JV, this analysis will compare 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 will argue that PTV licensees would adopt more costly studio installations and digital transmitters would be less efficient. This section develops this 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.

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 to most observers. The use of counterfactual analysis, pioneered by Robert Fogel and once extensively debated, has become well-accepted over the past twenty 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 impact population, the counterfactual for each is presented separately. However, the same economic framework will be used for evaluating benefits.

3.1.1 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] To accurately gauge AgileVision's impact, Sarnoff and Leitch provided comments on the system's application and market. This information permitted the creation of a counterfactual against which the benefits of AgileVision may be compared.

AgileVision is hypothesized to have a significant impact on PTV stations' costs for converting to DTV broadcasting. As will be explained later in this section, the first-generation AgileVision system's market consists of PTV stations 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. This section begins by explaining the AgileVision's PTV market scope. Next,

[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 effort for approximately two and a half years before it was purchased by Leitch. AgileVision is now the name of Leitch's product line incorporating JV technologies.

it compares AgileVision with the alternative system implementation and concludes with the hypothesized areas of economic benefit.

AgileVision and the Public Television Market

AgileVision is currently focused on the PTV member station market but intends to expand into the commercial station market in the future. The first generation system is not viable in the commercial station market because commercial stations originate a significant portion of their content. AgileVision is an integrated DTV broadcasting solution housed in one piece of equipment that simplifies the delivery of either four-channel standard definition (SDTV) feed or HDTV feed. Commercial and some PTV studio operations require full-scale digital studio equipment implementations that permit highly sophisticated manipulation of television signals, the alternative to AgileVision.

Three factors wed the first generation of AgileVision on the PBS market:

1. PBS is motivated by its mission to promote education and disseminate information. 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.

   Commercial stations have thus far been focusing on HDTV. 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 treat the May 1, 2003, digital conversion deadline very seriously and are planning and investing to ensure they adhere as closely as possible to the deadline. The PBS network held conferences and maintains task forces to facilitate member stations’ DTV rollout.

   Commercial stations, on the other hand, are moving more slowly. In general, they are opting to program and process signals in conventional analog technology and then encode their signals to digital for transmission. The deadline for commercial stations to begin digital transmission was May 1, 2002.

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, MPEG-2 compression 19.39 Mbps transport stream.

   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 three considerations, the scope of AgileVision's application is currently limited to the PTV market. As will later be discussed in Section 5, business drivers are emerging that will enhance AgileVision's viability for 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 at which time such viability will be realized.

Alternative System Implementation to AgileVision

As alluded to often in this report, the counterfactual to PTV stations' adoption of the AgileVision system is some alternative digital studio system implementation. In the absence of the JV, members indicated that AgileVision's enabling technologies, and therefore the system, would not have been developed. 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.

Information from South Dakota Public Broadcasting (SDPB) illustrates AgileVision's impact on studio configurations. The nine-station PTV network provided a comparison of their prospective costs for converting their studio broadcasting operations to DTV. AgileVision lowered their equipment costs by $1.1 to $2.2 million (SDPB, 2003; see Table 3-1). SDPB's cost savings were most concentrated in the areas of encoding equipment, studio automation, and video servers.

In addition to PBS network content, many member stations want to provide some of their own content, pass through only a part of the network feed, delay programs to another time slot, and/or add text and graphical content. And all need to correct the PBS-provided 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. PSIP correction is a technical requirement for all stations.

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.

Stations will also want to brand their content by inserting logos and station identification spots and must provide a vehicle (e.g., a message crawl) for the emergency broadcasting system (EBS).

Leitch representatives note that to accomplish the above tasks, 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.

Hypothesized AgileVision Benefits

This study hypothesizes that there are three economic benefits to AgileVision: equipment cost savings, installation cost savings, and on-going labor savings. The AgileVision system costs $225,000. 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. 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 AV box. According to Leitch, one engineer can accomplish the work that would take several people using an alternative technology.

3.1.2 Counterfactual to Digital Adaptive Precorrection (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 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'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 may have relaxed its spectral mask policy per the request of a consortium of transmitter manufacturers. In that case, equivalent DAP technologies may not have been developed, or if so, may have been introduced at a much later date.

However, postulating on potential policy outcomes ex post is contentious, particularly as 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. Thus, this analysis assumes that the FCC would have maintained its spectral mask requirements regardless of DAP's development and takes the approach of estimating the costs that all DTV stations would have otherwise incurred in the absence of DAP's development. 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 JV. The following discussion explores this scenario more fully and presents benefits and benefits population hypotheses.

Digital Transmitter Technological Innovation History, 1995 to 2000

Digital transmitters are "not a big technological leap" (Jessell, 1996). They 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).

The FCC planned for adjacent channel broadcasting, meaning that analog and digital signals would occupy adjacent channels in the television broadcasting spectrum. Historically, the FCC left empty channels between television signals to prevent the signals from interfering with one another. 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.[2] 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, most manufacturers focused their research efforts on developing new filtering technologies while the JV developed means for preempting out-of-band products (McConnell, 1995b). 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

[2]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)."

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.[3] 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 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 JV, nearly all digital transmitters would be operating less efficiently. The hypothesized DAP benefits population consists of all DTV transmitters that contain DAP or matching 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.

Equipment cost-savings consist primarily of the savings associated with incorporating less filtering technology into the transmitter installation.

[3] 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 in the late 1990s.

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

DAP also reduces installation costs. Adaptive precorrection 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 one-time equipment and installation cost savings. An additional automated benefit of DAP is that it permits transmitter supervisors to perform less-frequent manual adjustments to the transmitter's settings.[4]

3.1.3 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 the cost of the JV, which are simply the sum of the ATP and cost-share funds expended to develop JV technologies. As this analysis is evaluating the JV as a portfolio of projects, total expenditures are to be used, not just those for the development of DAP and the technologies embodied by AgileVision.

[4]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.

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.
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 Costs		
Total JV Costs	JV research and development labor and materials expenses.	Sum of ATP and JV members expenditures.

3.2 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 simplified Mansfield-type model and explains how it will be used to evaluate the success of the HDTV JV. This section concludes with a brief description of the primary metrics by which we will assess the economic benefits arising from ATP's investment in the JV.

3.2.1 Measuring the Benefits from Technological Change

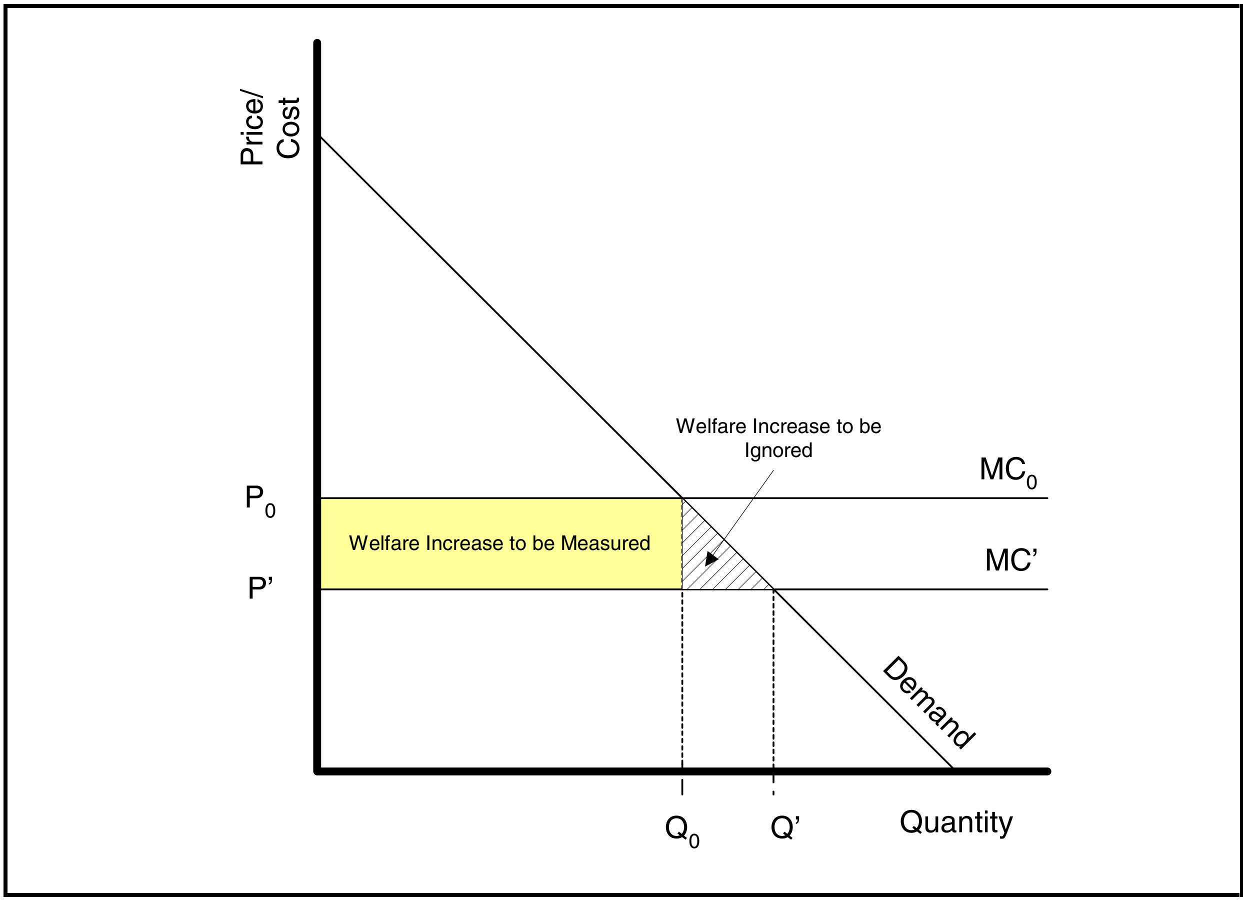
Technological change generates economic benefits through the creation of entirely new goods and services, as well as through improvements in existing products. Truly novel goods increase the overall satisfaction of purchasers by delivering experiences previously unobtainable; by improving buyers' level 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 introduction of televisions 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 more than adequate.

When cost or price reduction 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 firm's marginal cost of production from MC_0 to MC'. The firm can therefore cut its price accordingly, and with downward-sloping demand, will increase output and sales from Q_0 to Q'. The increase in social welfare includes the impact of the lower firm costs (the shaded rectangular area) and increase in demand due to a lower price (the triangle). In his empirical work, Mansfield measured the cost reduction benefits and ignored the smaller demand impacts.

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



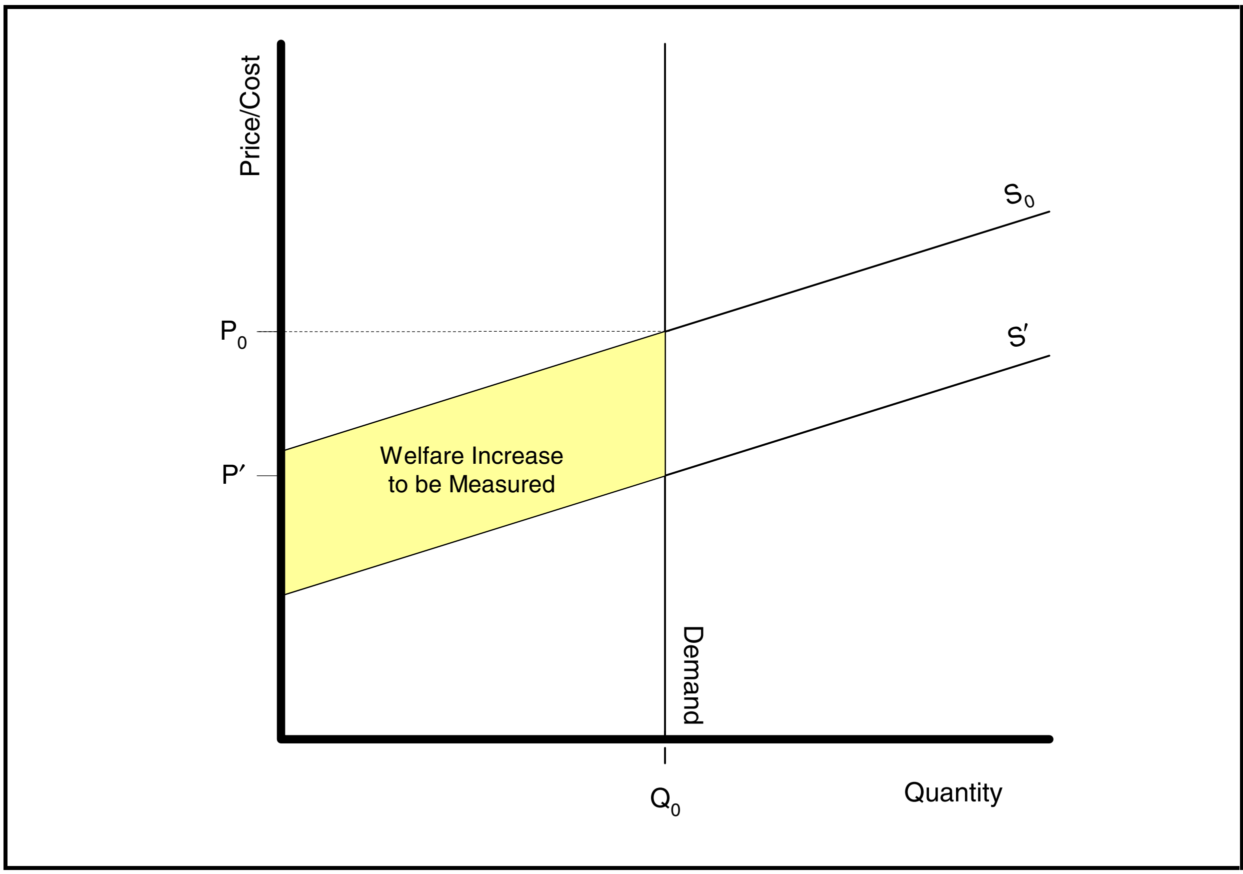
3.2.2 Approach to Measuring Benefits from the HDTV Joint Venture

In the current case study of the HDTV joint venture, 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 costs of choosing the defender option, and compare it to 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 Broadcast 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 over-simplification 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.

3.2.3 Metrics for Estimating Economic Benefits

The evaluation of the economic impact of the HDTV JV involved calculating several performance measures, summed across the two principal commercialized applications, the AgileVision system and DAP. Three of these 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 net benefits accrued in year t 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

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

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 ATP's contributions to the HDTV JV was calculated as

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

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. It should be noted that the 7-percent real discount rate required by OMB is a rather high hurdle for project analysis, ensuring that projects that showed a positive NPV were quite socially advantageous.

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 capital investments 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. It should be noted that in cases for which costs exceed benefits, an IRR cannot be calculated.

3.2.4 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 was 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 Economic Return

This section discusses the results of the economic analysis of AgileVision and DAP performed using the analysis framework outlined in Section 3. The economic analysis evaluates the joint venture's (JV's) economic benefit by employing the counterfactual scenario and quantifying technical and economic impact metrics.

The JV is evaluated as a portfolio. As such, the total quantifiable economic benefit from JV technology outcomes is compared to the costs for the entire JV. The AgileVision and DAP analyses differ both in terms or their scope and impact categories; the benefits quantification for AgileVision and DAP are therefore discussed separately. To evaluate the JV's net benefit and calculate measures of economic return, the benefits from each analysis are combined and compared with the JV's total cost.

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 JV project cost data.

This section presents

- the analysis and economic benefits of AgileVision,
- the analysis and economic benefits of DAP,

- time series of JV benefits and costs, and
- measures of economic return.

4.1 ECONOMIC BENEFITS ANALYSIS OF AGILEVISION

Public television (PTV) licensees that have adopted AgileVision have experienced one-time and on-going economic benefits. For these licensees, AgileVision lowered upfront equipment and installation costs and offered operations and maintenance savings. This analysis explores these benefits in further detail and develops an average benefit per licensee. The average benefit is then applied to a range of current and potential adopters to estimate economic benefits.

A licensee may be either a PTV station or system, such as WCNY in Syracuse, New York, or UNC-TV, North Carolina's statewide PTV network with 12 stations. It is important to note that PTV systems with multiple stations operate from a central broadcasting facility, known as a control point, and distribute their signal to their stations 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 station, assuming that each licensee has one control point.

The AgileVision analysis first quantifies the economic benefit per licensee. Next, it presents PTV licensee population and digital conversion time frame data. Many PTV licensees have yet to convert to digital television (DTV) broadcasting. The analysis examines the DTV conversion time frame and identifies potential adopters. It is challenging to project with great certainty how many potential adopters will actually adopt AgileVision. Hence, the total economic benefits are presented for 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. As shown in Table 4-1, total one-time savings are estimated to be $1.29 million; O&M savings are estimated to be $58,000 quarterly. The details behind these estimates are discussed 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	One-time
Installation Benefit	47,000	One-time
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 feed from 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, 2002)."

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

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 fits neatly into existing rack space.

AgileVision installation costs consist 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 man hours and average 39 man hours (AgileVision, 2001; Respondents). Based on installation cost data provided by respondents, this analysis estimates the AgileVision installation benefit to be $47,000, excluding any costs for studio renovation or expansion.[1]

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 net labor savings relative to the alternative system implementation.[2]

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 economic benefits, this analysis 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.

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[1] 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] 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.

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 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.

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.

Fifty-four licensees have converted or are converting to DTV broadcasting with an alternative system implementation.[4] Thus, 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 DPT with specific on air dates. For those licensees, this analysis assumed that the known future adoption time frame was representative and mapped those

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

[4]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 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.

licensees to an on-air date accordingly. Table 4-3 presents the estimated conversion time frame for all licensees.[5]

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 stations may choose AgileVision.

As a result, this analysis chose to estimate benefits over a range of total adopters, 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..

[5]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

Using the benefits per licensee and time trends for adoption, the total estimated adoption benefit of AgileVision ranges from $77.9 to $201.4 million through 2008, a 5-year time horizon from the date of this analysis. Table 4-4 summarizes the total economic benefits for the range of AgileVision market penetration.

Table 4-4. Total Estimated Public Television Licensee AgileVision Adoption Benefit, through 2008

	Low Market Penetration Rate (thousands)	Midpoint Market Penetration Rate (thousands)	High Market Penetration Rate (thousands)
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
Total	77,900	139,700	201,400

Note: All dollar values are in real, 2002 terms.

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 one-time 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 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 one-time 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	One-time
Installation Benefit	700	One-time
Operations & Maintenance Benefit	3,700	Ongoing quarterly benefit

Source: RTI estimates.

Equipment Cost Benefit

Digital filters are required to limit adjacent band interference in digital transmission. DAP dramatically reduces, but may not eliminate, the need for output filters on digital transmitters. Digital filters are used to mitigate out-of-band products, however DAP preempts much of the need for digital filtering by inserting equal and opposite effects to counteract them. "Such filters are expensive, take up space, and drive up the cost of installation (Jessell, 1996)." 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 DAP. DAP's benefit is in the set-up time required to configure the transmitter's settings. Although time is still required to ensure precise and accurate settings, DAP reduced the manpower that set-up required by over 10 hours. This analysis estimates the installation benefit to be $700 per digital transmitter.[6]

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.[7]

4.2.2 Digital Television Station Population and Digital Broadcasting Conversion Time Frame

The conversion to digital television is by no means complete. As of January 30, 2003, 733 stations were broadcasting in digital (NAB, 2003). However, there are 1,719 television stations in the United States

[6]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).

[7]The O&M labor benefit is calculated by multiplying the hourly benefit for transmitter supervisors 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.

(Federal Communications Commission [FCC], 2003). Therefore, nearly 1,000 stations have yet to complete the digital conversion process.

Secondary data sources were used to estimate on-air time frame 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, 2003; 100000watts.com, 2003; and RTI estimates.

Table 4-6 also presents the DAP benefit population of 1,651 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 $184.7 million through 2008 for the entire digital transmitter benefits population (Table 4-7). 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 2008

Year	Digital Adaptive Precorrection Benefit (thousands)
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
Total	184,700

Note: All dollar values are in real, 2002 terms.

Source: RTI estimates.

4.3 TIME SERIES OF JV BENEFITS AND COSTS

Sections 4.1 and 4.2 presented the total results from analyzing the quantifiable benefits of the JV. This section presents the JV's costs and creates a time series of benefits, costs, and net benefits for 1995 to 2008. These years encapsulate the beginning of the JV and a 5-year time horizon from the date of this analysis.

4.3.1 Joint Venture Costs

The JV was funded at 48 percent cost-share with JV members. In all, the JV cost $58.5 million, of which ATP provided $28.37 million (see Table 4-8). The balance of funds, $30.14 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. JV Costs, 1995–2000

Year	ATP Funding (thousands)	Non-ATP Cost Share (thousands)	Total (Nominal) (thousands)	Total in 2002$ (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 in real terms; therefore the JV costs were adjusted to 2002 dollars, as well. The BLS online inflation calculator, based on average Consumer Price Index (CPI) data, was used to make this adjustment for inflation (BLS, 2003). In real 2002 dollars, the JV cost $64.8 million.

4.4 MEASURES OF ECONOMIC RETURN

In this section, four measures of the benefits of the JV are calculated: net benefits, the benefit-cost ratio, the net present value (NPV), and the internal rate of return. This section also breaks out and discusses realized benefits from the total benefits estimate.

4.4.1 Time Series of Net Benefits and Measures of Economic Return

The net benefit of the JV lies between $197.9 and $321.3 million (see Table 4-9). The range of benefits expressed in Table 4-9, $262.7 million to $321.3 million, is the sum of DAP benefits and the AgileVision estimated range of benefits, less the ATP and JV-member expenditures. As mentioned previously, net benefits are expressed as a range because AgileVision's benefits were calculated for a range of market penetrations.

Table 4-9. Time Series of Costs, Benefits, and Net Benefits, 1995–2008

	Net Benefits		
Year	Low (thousands)	Midpoint (thousands)	High (thousands)
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	5,300	5,300	5,300
2002	17,400	17,400	17,400
2003	68,700	104,000	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
Total	197,800	259,600	321,300
NPV of Net Benefits (1995-2008)	78,000	109,000	139,900
Benefit to Cost Ratio	2.52	3.13	3.73
Social Rate of Return	22.5%	26.6%	30.1%

Note: All dollar values are in real, 2002 terms.

Source: RTI estimates.

ATP and JV members incurred costs from 1995 through 2000. Benefits accrued prior to the JV's end because Thales released transmitters with DAP to the market after completing its research within the JV's original 3-year time frame.

Three additional measures of economic return are provided in Table 4-10. 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 $78.0 million and $139.9 million. The benefit-to-cost ratio is between 2.52 and 3.73 and the social rate of return is between 22.51 percent and 30.1 percent.

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

	JV Benefits (thousands)			JV Costs (thousands)	Net Benefits (thousands)		
Realized							
Real (2002$)		109,800		64,800		45,000	
NPV (1995-2008)		55,700		51,200		4,500	
	Low	**Midpoint**	**High**				
Potential							
Real (2002$)	152,800	214,600	276,300				
NPV (1995-2008)	73,500	104,500	135,400				
	Low	**Midpoint**	**High**		**Low**	**Midpoint**	**High**
Total							
Real (2002$)	262,600	324,400	386,100		197,800	259,600	321,300
NPV (1995-2008)	129,200	160,200	191,100		78,000	109,000	139,900

Source: RTI estimates.

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 realized benefits 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 2008. 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.

JV realized benefits total $109.8 million (see Table 4-10). As JV costs were sunk in the late 1990s, the realized net benefits are $45.0 million when subtracting $64.8 million in costs. The NPV of realized net benefits is $4.5 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 increases to between $78.0 million and $139.9 million over the 1995 to 2008 evaluation period of the analysis.

5 JV Technologies: Looking Forward

In addition to examining the quantitative impacts of the HDTV JV, this analysis also compiled information about the future directions of JV-developed technologies. Not all JV technology outcomes were commercialized, but nearly all have had some sort of impact on the future direction of R&D in their respective functional areas. Indeed, even those JV 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 JV technologies in a broader context and to present known details on their future application.

5.1 QUALITATIVE REVIEW OF THE HDTV JV

A significant outcome of the JV 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 JV, 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 digital television challenges. Indeed, JV members pointed to product offerings from nonmembers, technical roadmap articles, and other evidence that included kernels of their research.

This knowledge may not have been generated had it not been for ATP's involvement. JV members unanimously agree that the JV would not have occurred in the absence of ATP involvement. ATP's funding support permitted JV members 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's R&D outcomes are summarized in Table 5-1. The JV set for itself seven technical goals, all of which were successful, though only five have been incorporated into commercial products. Those that have not found full-scale commercial outlets that still have an impact. IBM and Sun both indicated that their R&D efforts (goals six and seven in Table 5-1) are molding approaches to new product development efforts.

Therefore, it is likely that the JV has additional benefits that have yet to accrue. 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 IBM or Sun 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 their 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.

5.2 MARKETS BEYOND DTV BROADCASTING

In the statement of work for this project, RTI was asked to evaluate JV technologies' potential for markets beyond 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 their equipment was up and running before the JV started. But some technologies, particularly IBM's and Sun's research, would be applicable in any market where routing and query of video data was needed.

Table 5-1. 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 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 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 AgileVision system.
4	Digital adaptive predistortion 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	No	Sun: briefly had products available. IBM: some technology transfer through consulting agreements.

Source: NIST, 2001.

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 PTV stations. Indeed, in terms of relative value, the PBS member stations, and therefore their constituencies, may be the single-largest beneficiary of the JV. Looking forward, AgileVision has two other prospective areas of benefit: commercial television broadcasting and datacasting.

5.2.1 AgileVision and Commercial Television Broadcasting

AgileVision's multicasting capability 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.

5.2.2 AgileVision and Datacasting

Datacasting refers to the broadcast of data 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 onscreen or save it to a hard drive for later use" (2003).

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. AgileVision itself is not a datacasting tool, but it provides a platform from which datacasting can be accomplished. AgileVision was designed to integrate with other pieces of digital studio equipment and to be scalable. Broadcasters would be able to integrate supplemental datacasting equipment with the system and commence operations. One of the stations interviewed indicated that AgileVision lowered future datacasting equipment costs, but could not enumerate an estimate.

Although the JV did not investigate datacasting specifically, 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.

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