

Planning Report 12-1

The Economic Impacts of
Documentary Standards:
A Case Study of the Flat
Panel Display Measurement
Standard (FPDM)

David P. Leech
TASC, Inc.

John T. Scott Ph.D.
Consultant
Dartmouth College

December 2011

NIST

**National Institute of
Standards and Technology**
U.S. Department of Commerce

GCR G2012-0299

**The Economic Impacts of Documentary Standards:
A Case Study of the Flat Panel Display Measurement
Standard (FPDM)**

David P. Leech

John T. Scott Ph.D.

GCR G2012-0299

**The Economic Impacts of Documentary Standards: A Case
Study of the Flat Panel Display Measurement Standard
(FPDM)**

**Prepared for
National Institute of Standards and Technology, Standards Coordination Office**

This publication was produced as part of contract SB134109NC0286 with the National Institute of Standards and Technology. The contents of this publication do not necessarily reflect the views or policies of the National Institute of Standards and Technology or the US Government

David P. Leech
TASC, Inc.
John T. Scott Ph.D.
*Consultant
Dartmouth College*

December 2011



U.S. Department of Commerce
John E. Bryson, Secretary

National Institute of Standards and Technology
Patrick D. Gallagher, Director

ES. Executive Summary

One of the functions of NIST and its Standards Coordination Office (SCO) is to assist U.S. industry with the standards-related tools and information it needs to compete more effectively in the global marketplace. This analysis is one of a series of NIST assessments that focus on examining the economic impacts of documentary standards. Its purpose is to assist NIST in more effective leveraging of the expert resources that it devotes to the development of voluntary consensus standards.

Each year as many as four hundred NIST experts are involved in more than 1000 private sector-led documentary standards committee activities. With this high level of resource commitment, NIST expertise and resources should be focused on areas that have the highest potential impact and likelihood of achieving NIST's goals and objectives. This economic impact assessment contributes to understanding how that is achieved.

The selection of the Video Electronics Standards Association's (VESA's) Flat Panel Display Measurement (FPDM) standard was based on pragmatic criteria namely, availability of information, but was, in retrospect, fortuitous. The history of the FPDM project, and the investigation of the way in which NIST's know-how is developed and enters the stream of industry value creation provides many lessons learned. The development of similar case studies may well provide the foundation for a richly informed understanding of why such engagements with industry succeed and fail. Not only was the FPDM a success from an economic impact perspective, but it is also the story of the role documentary standards can play in a global knowledge-based growth industry and how a NIST "core competency" (measurement technology), in partnership with industry, can hold important keys to innovation and economic growth.

In 1992, just a few years after the Omnibus Trade and Competitiveness Act of 1988 changed the name of the National Bureau of Standards (NBS) to the National Institute of Standards and Technology (NIST), the Flat Panel Display Laboratory (FPDL) was established at the Gaithersburg campus of NIST¹. Much like today, global competitiveness and innovation was of foremost concern and helped provide a catalyst for the US investment in flat panel technology. But the ultimate success of the FPDL and the FPDM standard is not centrally a story about competitiveness. Rather, it is a story of how innovation was fostered from the close collaboration of industry and NIST, solving difficult technical and commercial problems using NIST's unique resources, in exactly those areas where such collaboration is *least* controversial — standards development. Acting alone, industry would have faced difficult proprietary and technical barriers. In this case, NIST was able to help by exercising its essential roles as an *honest broker* and a *conduit* for the highest international standards based on good measurement practice. As part of VESA's FPDM Workgroup, NIST experts worked hand-in-hand with industry display measurement leaders. This collaboration helped accelerate the transfer of measurement know-how, and the application of flat panels to a wide array of industries at a cost that, working alone, industry would have been highly unlikely to achieve.

¹ The laboratory was moved to the Boulder campus in 2003.

While not without its critics, the FPDM Workgroup produced a measurement standard unlike any other by most accounts. And all agree that NIST’s technical staff made a great difference. In addition to technical expertise, and probably largely because of it, NIST forged a close and effective relationship with its industry counterparts. The result of this collaboration included: expansion of markets, increased product quality for a rapidly expanding array of products, and lower costs of production. In the words of a prominent industry spokesman, “displays are becoming pervasive throughout today’s information society, and having a uniform and consistent means of measuring and evaluating them is essential.”

Through the collaborative efforts of VESA’s FPDM Workgroup, with NIST as a partner, the project developed and transferred measurement technology; codified display measurement know-how in a comprehensive measurement standard (FPDM); enabled annual savings of thousands of hours of metrology operations within firms and additional hundreds of hours in SDO consensus-making efforts (not only for VESA but for other SDOs that adopted FPDM as part of their own related work); and effected the application of flat panel technology to ever-widening uses to the benefit of the consuming public.

This economic impact assessment estimates only selected areas of the FPDM’s economic impact: industry metrology labor savings that resulted from the adoption of FPDM, and the consensus-making efficiencies resulting from NIST’s participation in VESA’s FPDM Workgroup. As only these impacts are captured in this analysis, the estimates of economic impact shown in Table ES-1 are highly conservative.

Table ES-1. Estimate of Economic Impact

Performance Metric	Value
Net Present Value in 1992	\$15,573,930
Net Present Value in 2010	\$56,323,545
Real Social Rate of Return	48%
Benefit-to-Cost Ratio	4

Even as a very conservative estimate of the project’s outcome, the FPDM’s economic impact is impressive. With the availability of better data the estimate of the impact of the FPDM would be considerably higher and would capture:

- FPDMs impact on the quality of products that use FPDs and the consumer benefits that accrue from such quality improvements
- The value to industry of measurement device designs that were a product of NIST’s role in the FPDM Workgroup
- Extra benefits to industry of releasing the FPDM sooner than it would have been released, due to NIST’s participation
- The codified know-how carried forward into the International Committee on Display Measurement’s (ICDM’s) forthcoming Display Measurement Standard (DMS).

Table of Contents

ES. Executive Summary	ii
List of Figures	v
List of Tables	v
1 Introduction	1
1.1 What is a Documentary Standard?	1
1.2 NIST’s Role in the Documentary Standards Process	1
1.3 NIST’s Standards Coordinating Office	3
1.4 Assessing the Economic Impact of Documentary Standards at NIST	3
1.5 Flat Panel Display Measurement Standard (FPDM)	4
1.6 ICDMs Display Measurement Standard (DMS).....	6
2 Background	7
2.1 Development and Take-Off of the Flat Panel Display Industry	7
2.2 Flat Panel Display Metrology	10
2.3 Establishment of NIST’s Flat Panel Display Laboratory (FPDL)	11
2.4 Video Electronics Standards Association (VESA) FPDM Workgroup.....	14
2.4.1 VESA.....	14
2.4.2 FPDM Workgroup.....	14
3 Economic Analysis Framework.....	17
3.1 Documentary Standards as “Infratechnology”	17
3.2 An Economic Perspective on the Genesis of a the FPDM	19
3.3 The Economic Implications of FPDM Workgroup Inputs and Outputs	26
3.3.1 FPDM: Codified Measurement Know-How	26
3.3.2 FPDM-Related Metrology Equipment Design	28
3.3.3 SDO Process Efficiencies	29
3.4 Affected Organizations: Industry Structure.....	31
4 Assessment Framework and Approach.....	33
4.1 Expected Outcomes	33
4.2 Barriers to Innovation.....	34
4.3 Comparison Scenario.....	36
4.4 Economic Impact Timeframe (1992-2010)	38
4.5 Economic Impact Variables.....	38
5 Survey Findings	39
5.1 Survey Strategy, Population, and Sample.....	39
5.2 Qualitative Findings	40
5.3 Quantitative Findings	42
6 Quantitative Analysis	44
6.1 Benefits.....	44
6.2 SDO Costs and NIST Expenditures.....	45
6.3 Measures of Economic Impact	46
7 Conclusion.....	50
Appendix A: Types of Documentary Standards ISO/IEC Guide 2: 2004	53
Appendix B. Flat Panel Display Laboratory Publications and Presentations	54
Appendix C. FPDM Standard Economic Impact Survey Instrument.....	67
Appendix D. Economic Impact Metrics.....	73

List of Figures

Figure 3-1. Flat Panel Display Industry Value Chain	31
---	----

List of Tables

Table ES-1. Estimate of Economic Impact	iii
Table 2-1. Market Growth by Selected FPD Applications.....	9
Table 3-1. Documentary Standards Economic Benefit Matrix	18
Table 3-2. Quality Dimensions for Documentary Standards	29
Table 4-1. Sources of Cost-Reduction Benefits from FPDM.....	34
Table 6-1. FPDM-Related Benefits (Nominal \$)	45
Table 6-2. FPDM Workgroup Costs and NIST Expenditures (Nominal \$)	46
Table 6-3. Constant 2010 Dollar Benefits and Costs (1992 - 2010)	47
Table 6-4. Estimate of Economic Impact	48

Acknowledgments

The authors want to acknowledge the guidance and judgment provided by Erik Puskar and Mary Donaldson of NIST's Standards Coordination Office over the entire course of study effort, from conceptualization to final editing. Extensive communications with knowledgeable technical experts and industry participant-observers were indispensable for the authors' understanding of the flat panel industry and display measurement. While input from many technical experts was received, we wish to specifically thank the following individuals for their contributions without whose guidance this study would not have been completed; Paul A. Boynton (NIST Quantum Measurement Division), Edward F. Kelley, Joe Miseli, Thomas P. Murtha, Mark Fihn, and Phil Downen. We are also grateful to Greg Tassej for his review of the paper.

1 Introduction

1.1 What is a Documentary Standard?

There are two different types of standards -- *physical measurement* standards and *documentary* standards.²

The National Institute of Standards and Technology (NIST) is responsible for developing, maintaining and disseminating national *physical measurement* standards for basic measurement quantities (such as mass, time and frequency), which are traceable to the International System of Units (SI). Together they promote order, efficiency, and fairness in the marketplace, facilitate technological progress, and ultimately enhance U.S. competitiveness.

Documentary standards are written agreements among producers and/or users of products and services containing technical specifications or other precise criteria that may contain rules, guidelines, or definitions of characteristics. These standards ensure that materials, products, personnel qualifications, processes, and services are adequate for their purpose, compatible and/or interchangeable, if necessary; ensure public health and safety; protect the environment; and/or improve economic performance.

Documentary standards³ can specify product characteristics, establish accepted test methods and procedures, characterize materials, define processes and systems, or specify knowledge, training and competencies for specific tasks.

Frequently (perhaps optimally), *documentary* standards act as a bridge connecting national representations of international physical measurement standards to the day-to-day operations of industry in their research and development (R&D) efforts; in the application of this R&D to new technologies and innovations; and in transitioning new products and services into growing markets.

1.2 NIST's Role in the Documentary Standards Process

NIST has a variety of roles in the private sector-led U.S. voluntary standards system. First, NIST frequently provides research and measurements that establish the underpinning for standards, ranging from materials test methods to standards for building performance, and for a range of technologies, from information and communications technologies to nano- and bio-technologies. Second, NIST's staff members often participate in the preparation of the standards documents through their work on private sector-led standards committees and, in support of those committees, develop and organize workshops, seminars, and conferences.

² Maureen A. Breitenberg, *The ABC's of Standards Activities* (NISTIR 7614), August 2009, National Institute for Standards and Technology.

³ ISO/IEC Guide 2: 2004, Standardization and related activities -- General vocabulary, provides general terms and definitions concerning standardization and related activities. See Appendix A for types of documentary standards.

Third, under the National Technology Transfer and Advancement Act (NTTAA), NIST is responsible for coordinating federal, state and local activities in voluntary standards and working with industry and government to develop and apply technology, measurements and standards. Fourth, NIST is responsible for chairing the Interagency Committee on Standards Policy (ICSP), which helps to ensure effective participation by the federal government in domestic and international standards and conformity assessment activities and promote the adherence to uniform policies by federal agencies in the development and use of standards and in conformity assessment activities.

In addition, NIST is responsible for the following efforts:

- National Inquiry Point on Technical Barriers to Trade⁴
- National Voluntary Laboratory Accreditation Program (NVLAP)⁵,
- Maintaining the fundamental physical standards, such as length, time and frequency and units of mass, which underlie measurements contained in standards.⁶

NIST coordinates its standards role with that of the private sector through a Memorandum of Understanding (MoU) with the American National Standards Institute (ANSI).⁷ The MoU is intended to improve domestic communication and coordination

⁴ The National Inquiry Point on Technical Barriers to Trade provides research services on standards, technical regulations, and conformity assessment procedures for non-agricultural products to assist in carrying out the U.S. government's responsibilities under the World Trade Organization (WTO) Agreement on Technical Barriers to Trade (TBT).

⁵ The NVLAP provides third-party accreditation to testing and calibration laboratories in response to Congressional mandates or administrative actions by the Federal Government or from requests by private-sector organizations. The NAVLAP operates in conformance with International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) standards, including ISO/IEC 17025 and ISO/IEC 17011.

⁶ These fundamental physical standards are national realizations of standards of measurement agreed to by the International Committee for Weights and Measures (CIPM) under the Treaty of the Meter. The CIPM establishes, maintains, and disseminates the International System of Units (SI). These SI definitions are stated without uncertainties. To be useful, SI definitions require physical artifacts or experimental apparatuses that generate realizations of the SI units. Generating and maintaining such realizations is the business of NIST and similar national metrology institutes in other countries. For an example of how this system works in a specific instance — the volt — See, D. Leech, *Economic Impact Assessment of the NIST's Josephson Volt Standard Program*, (Planning Report 01-1), NIST, July, 2001, pp. 4-7.

⁷ ANSI has served as administrator and coordinator of the United States private sector, voluntary standardization system for almost 90 years. ANSI is a private, not-for-profit membership organization supported by a diverse constituency of private and public sector organizations including government agencies, companies, academic and international bodies, and individuals. ANSI accredits U.S. standards developers using criteria based on international requirements. ANSI has accredited over 200 standards developers in the private and public sectors. These accredited Standards Developing Organizations (SDOs) develop standards based on consensus and other principles, and can choose to publish such standards as American National Standards (ANS). ANSI is the sole U.S. representative and dues-paying member of the two major non-treaty international standards developing organizations, the International Standards Organization (ISO) and the International Electrotechnical Commission (IEC). Through ANSI, the U.S. has immediate access to the ISO and IEC standards development processes. ANSI administers many key ISO and IEC committees and subcommittees.

among both private and public sector parties in the United States on voluntary standards issues and increases the effectiveness of U.S. government agency participation in the national and international voluntary standards-setting process.

1.3 NIST's Standards Coordinating Office

One of NIST's central missions is to assist U.S. industry by providing standards-related tools and information it needs in order to compete more effectively in the global marketplace. The Standards Coordination Office (SCO) within NIST supports this mission by conducting standards-related programs, and providing knowledge and services including the monitoring of global standards developments and conformity assessment activities.

Under the aegis of the National Technology Transfer and Advancement Act of 1995 (NTTA), SCO manages the coordination of federal, state, and local technical standards and conformity assessment activities, as well as coordinating with those in the private sector. SCO coordinates the activities of the Interagency Committee on Standards Policy, and participates in the Commerce Standards Committee and operates the Global Standards Information website.⁸

To execute its responsibility, SCO offers training, publications, policy analysis, and research and information services and works closely with U.S. industry, standards developers, other government agencies in the global standards community to maintain and improve a technological infrastructure that supports innovation and economic growth.

1.4 Assessing the Economic Impact of Documentary Standards at NIST

Promoting U.S. innovation and industrial competitiveness is part of NIST's mission. One of NIST's core competencies is to contribute to the development and use of sound technical standards. To form a comprehensive picture of NIST's documentary standards development activities, in 2008 NIST labs and centers were canvassed to answer the question: *How well is NIST doing in this area?* The laboratories and centers were asked to identify instances where NIST has played an active role in the development or implementation of documentary standards.⁹ At the time of the canvassing, SCO identified 404 NIST personnel involved in 1398 documentary standards committees. Seventy-eight of those canvassed reported their involvement in what they regard as "high-impact" documentary standards efforts.

Over time NIST wants to develop a reliable approach to understanding and assessing its influence on standards development processes so as to better monitor performance and

⁸ The Interagency Committee on Standards Policy (ICSP) advises the Secretary of Commerce and other Executive Branch agencies in standards policy matters, and reports to the Secretary of Commerce through the Director of the National Institute of Standards and Technology (NIST). The Committee's authority is set out in Section 13 b of OMB Circular No. A 119.

⁹ Erik Puskar, *Selected Impacts of Documentary Standards Supported by NIST* (NISTIR 7548), U.S. Department of Commerce, National Institute of Standards and Technology (NIST), 2008.

assess impacts. SCO wants to gain an understanding of the best way to allocate NIST resources to documentary standards development projects and the best circumstances in which to engage the standards development community. Several of the self-reported “high-impact” documentary standards projects were selected for further analysis and two were selected as potential candidates for quantitative economic impact assessment. The Flat Panel Display Measurement standard development project was selected for initial quantitative impact assessment. Unlike other impact assessments conducted by NIST, one of the goals of this assessment project is to discern attributes of the documentary standard development process that appear to affect impact. In the future, a collection of such attributes from across impact assessments will be tested for their potential as “leading indicators” of the economic value of NIST’s participation in the development of specific documentary standards.

1.5 Flat Panel Display Measurement Standard (FPDM)

Flat-panel displays (FPDs) are a class of advanced display technologies that have emerged to replace traditional cathode ray tubes because of advantages in weight, power needs, resolution, and high information content. There are several technologies competing for market share, and a number of niche applications. (See section 2.1 below, for a more detailed discussion of the evolution of FPD technology.)

In the vernacular of ISO/IEC Guide 2: 2004, the FPDM is a “testing standard.”(See Appendix A.) According to industry metrologists, the FPDM standard has become the *de facto* “standard of standards,” serving the display industry with a comprehensive catalog of versatile optical measurements and informative technical discussions well grounded in metrology. According to one participant observer in the FPDM development process,

“No other standard offers so much practical information organized so well.”^{10,11}

In May, 1998, the FPDM was released by the FPDM Workgroup of the VESA Display Committee (discussed in section 2.3 below). It was developed to fill a void in FPD metrology. Other standards spoke to the issue of *what* to measure but nothing had been published on *how* to measure and how to avoid the pitfalls of inadequate metrology.¹²

In 1994, prior to the publication of FPDM 1.0 (1998), a NIST workshop on display standards concluded that few companies could afford to follow all the display standards

¹⁰ Phil Downen, “A Closer Look at Flat Panel-Display Measurement Standards and Trends.” *Information Display*, No. 1, 2006.

¹¹ Not all well-informed observers agree with this accolade. One expert voiced the opinion that the FPDM was not even a “standard” in the ordinary sense that it focused on one way to measure “X.” And in this expert’s opinion, the FPDM introduced some inefficiencies into the display industry as a result. The preponderance of opinion seems to be closer to Downen’s view, *Ibid.* That said, the view that FPDM is not an ordinary standard will be used to support the evaluation strategy explained in section 4.3 of this report.

¹² *Ibid.*, p.16. Other relevant standards emphasized: physical aspects of the human-display interface, and classified displays in terms of viewing direction, contrast and color, reflection performance and pixel faults to determine the suitability of a display for the office environment (ISO 13406-2, “Ergonomic Requirements for Work with Visual Display based on Flat Panel”); compliance mandates

activities; that it would be helpful for industry metrologists to have access to the latest measurement developments; and that users of displays (companies that integrate displays into their products) need a bedrock of measurement standards to enable their choice of the best display for their application.

Metrologists from NIST and industry's David Sarnoff Research Center National Information Display Laboratory (NIDL) initiated a survey of existing display standards.¹³ The authors — all seasoned display metrologists — reported a blossoming of display applications and technologies and the growing interdependence of users and manufacturers of display devices.¹⁴ This, in turn, was driving a proliferation of standards-making efforts characterized, unfortunately, by “a great deal of overlap among the various display standards.” And yet the methods of measurement among the various standard were not the same.” According to the report, “one finds a wide range of detail describing precisely how any measurement is to be made and reported.”¹⁵

Prior to the development of FPDM, a producer or buyer of flat panel displays (FPDs) would consult any (or all) of a number of existing standards, depending on the specific application.¹⁶ In the absence of FPDM (1998), a producer and/or buyer would have to expend considerable resources working out which measurements best suited a given need; working out the numerous technical measurement inconsistencies among the various measurement standards; and negotiating agreement on chosen metrics and measurement procedures to be used in qualifying a FPD for future use, or in assessing the quality of the FPDs provided by manufacturers to integrators or users.

The FPDM resolved many of these technical difficulties by offering a measurement standard with a set of measurement procedures that is unambiguous, that applied to multiple display technologies, and that was practical and cost-effective to utilize.

¹³ The National Information Display Laboratory (NIDL) was part of the David Sarnoff Research Center (itself an early pioneer in liquid crystal display materials and flat panel display technology during the 1960s and early 1970s) and conducted “third party evaluations” (like an “Underwriter’s Laboratory) for technically sophisticated government and corporate clients. (Personal communication with Michael Grote, April 5, 2010, former NIDL employee who was also active and VESA’s FPDM Workgroup.)

¹⁴ This observed “growing interdependence of users and manufacturers of display devices” signaled an important industrial transition that, it is hypothesized, opened the door for NIST to play an important role in a booming global industry. See the discussion in section 3.2 below.

¹⁵ Edward Kelley et al., “A survey of components of display-measurement standards, *Journal of the SID*, No. 3/4, 1995, pp. 219-222.

¹⁶ The array of standards a display metrologist would consult included ISO 9241 (Parts 3, 7, 8) and ISO 13406 (draft 2); ANSI HSF-100 (1988) and IT7.215 (1992); EIA TEB (27) and TEP (105); VESA Display Specifications and Test Procedures (for CRTs); NIDL’s Procedures for Evaluation and Reporting the Capabilities of High Performance Display Monitors for Imagery Applications; SAE ARP 1782 and ARP 4260; MRP 1990:8 (1990:10);USAF AFGS 87213A; and IEC SC 47C. ISO – International Standards Organization; ANSI – American National Standards Institute; EIA – Electronic Industries Association; EC – International Electrotechnical Commission; SAE – Society of Automotive Engineers; MRP – Swedish National Board of Measurement and Testing; NIDL - National Information Display Laboratory; USAF – United States Air Force. See, Edward F. Kelley, George R. Jones, Paul A. Boynton, Michael D. Grote, and Dennis J. Bechis, “A Survey of the Components of Display Measurement Standards,” *Journal of the Society for Information Display*, Vol. 3, No. 4, December 1995, pp. 219-222.

1.6 ICDMs Display Measurement Standard (DMS)

Display products have evolved at a fast pace. To keep up with those changes further revisions of FPDM have been necessary. In 2007, the FPDM Workgroup efforts, including the NIST representatives, were transferred from VESA to the Society of Information Display (SID) and the International Committee for Display Metrology (ICDM) was formed as part of SID's Definitions and Standards Committee. The ICDM included the core group of individuals who wrote the existing versions of FPDM with expanded participation of world experts from within the SID membership in the area of display evaluation. Experts of the Committee Working Group include display engineers, metrologists, color scientists, vision scientists, university researchers, human-factor specialists, and ergonomists. The third version of what was the FPDM — now, the Display Measurement Standard (DMS) — is expected to be released in 2011.

2 Background

2.1 Development and Take-Off of the Flat Panel Display Industry¹⁷

Flat-panel displays are a class of advanced display technologies that have emerged to replace traditional cathode ray tubes (CRTs) because of advantages in weight, power needs, high resolution, and high information content. There are several technologies competing for market share, and a number of niche applications. During the 1980s, pushed by leading Japanese companies, liquid crystal displays (LCDs) became the dominant commercial display technology. LCDs in turn come in two types: active and passive matrix LCDs. The more advanced (active matrix) AMLCDs, consist of a thin film transistor (TFT) attached to each of hundreds of thousands of pixels (short for picture elements) that together form an image on a television screen).

FPD technologies include plasma display panels (PDPs), in which ionized gases produce the light; field emission displays (FEDs), an improved cathode ray technology that combines with semiconductor technology; and electroluminescent displays (ELDs), which generate light from phosphorus, sandwiched between electrodes. All of these technologies are high-information content displays, capable of containing large amounts of information required, for example, in high-definition television and computer displays. Not all LCDs are high information; there is still a large market for low-information LCDs in such items as wristwatches, calculators, thermometers, and appliances. Though U.S. companies pioneered the technology, today Japanese, Korean, and, increasingly, Chinese companies control the lion's share of the world market.

Beginning in the 1960s, and throughout the 1970s and 1980s, scientists and product developers in the U.S. (at RCA, IBM, Westinghouse, Texas Instruments, Hughes Aircraft, Rockwell, ATT, to name some familiar U.S. corporate R&D powerhouses), and their Japanese partners and competitors (prominently Sharp, Seiko Epson, Suwa-Seikosha, and Hitachi) worked to perfect display technologies that would eventually make giant, wall-hanging, flat TV sets possible—and affordable—for any household. Along the way, Japanese, U.S., and European firms developed products and commercialized a dizzying array of underlying material, component, and device technologies such as instrument read-outs, wristwatch displays, calculator displays, personal digital assistants, and, eventually, small TV screens (primarily in the 3-5 inch range).¹⁸

¹⁷ This section is based on Thomas Murtha, et. al., *Managing New Industry Creation: Global Knowledge Formation and Entrepreneurship in High Technology*, Stanford University Press, 2001; Claude Barfield, *High-Tech Protectionism*, AEI Press, December 2003; Joseph Castellano, *Liquid Gold: The Story of Liquid Crystal Displays and the Creation of an Industry*, World Scientific Publishing Company, 2005; and John A. Mathews, "Strategy and the Crystal Cycle," *California Management Review*, Vol. 47, No. 2, Winter 2005, pp. 6-32.

¹⁸ The first flat panel TV was is attributed to John van Raalte of RCA. He demonstrated the first off-air moving TV on an LCD in 1967. Sanyo Electric & Sanritsu Electric together build the first 3-inch color AMLCD TV using alpha-Si:H in 1983. In 1987, GE's R&D Center in New York built the first 88-inch color TV utilizing an AMLCD with alpha-Si:H TFTs and Hitachi introduced a 5-inch color TV using

Throughout the 1980s flat panel computer displays were also being developed. In 1988, IBM and Toshiba developed a prototype for what would prove to be the first “killer app”: 14-inch working prototypes of color liquid crystal displays.¹⁹ According to industry observers, by the early 1990s, the FPD industry stood on the brink of taking off. In early 1992, IBM Personal Computer Company had received orders for more than 100,000 units of the *Thinkpad* (which utilized a 10.4-inch DTI color display). “The 14-inch thin-film-transistor (TFT) LCD demonstrations sounded the starting bell in the knowledge race to create high-volume manufacturing processes for large-format, color FPD production.”²⁰

And yet the 14-inch prototypes did not establish the underlying TFT LCD technology as a standard. Development continued in a number of alternative FPD technologies. The demonstrations did not establish a dominant design for TFT LCDs either. “The products continued to evolve on multiple dimensions, including size, video response rates, color subtlety, viewing angle, power consumption, and weight, just to name a few.”²¹

Many technical performance limitations on TFT LCDs could only be solved by the accumulation of manufacturing process knowledge, as well as its embodiment in successive generations of manufacturing equipment and materials.²² But as these

AMLCD with alpha-Si:H TFTs. In 1988, the Japanese government sponsored a consortium (chartered by MITI) with the goal of developing a 40-inch wall-hung TV. Developing a 40-inch HDTV by 1998 was the goal of the Japanese High-Vision PDP Consortium launched in 1994. In that same year, NIST’s FPDL published papers on measuring noise in TV receivers and TV displays. In 1996 Mitsubishi acquired Plasmaco for the promise of its PDP technology for HDTV. Samsung built the first 30-inch color TFT-LCD for TV in 1997. In 1998, the large PDP TV that was the goal of Japan’s High-Vision PDP Consortium, launched in 1994, was demonstrated at Nagano Olympic Games and Sharp announced its first complete line of flat HDTVs. Plasma TVs started to significantly penetrate the high-end consumer market by 2000, the same year that Planar Systems (the leading U.S. manufacturers of EL displays) exited the market for military displays. By 2003, a 52-inch and a 55-inch color TFT LCD display was available from LG Philips for TV to market, and 54-inch and 58-inch color TFT LCD display was available from Samsung. That year (2003) was also the year that FPDs eclipsed CRTs in their share of world market value and the year that Samsung and Sony formed the S-LCD panel production alliance that propelled Sony Bravia to the global TV market share lead in 2006. These historical citations are taken from Mutha, et. al., *op cit.*; and Castellano, *op cit.*

¹⁹ Seiko Epson and Grid Systems introduced portable computers to the U.S. in 1982, the later with a display supplied by Sharp. In 1983, Kyocera built the first portable computers with passive LCDs. These were used in models sold by Tandy, NEC, and Olivetti. Sharp began high-volume production of STN-LCDs for notebook computers in 1986. In 1988, IBM and Toshiba jointly developed a 14.3 flat panel display using active matrix technology, and, in 1989, NEC, Toshiba, Sharp, Mitsubishi introduce portable computers with color screens. Mutha, et. al., *op cit.*; and Castellano, *op cit.*

²⁰ Murtha, et. al., *op. cit.*, p. 11.

²¹ Ibid.

²² Ibid. Generation 2 manufacturing lines were in place by mid-1994. The AKT-1600, a four-chamber production system, sold for about \$5 million and could process approximately forty substrates per hour. High-volume fabs needed about four of them. Murtha, et. al., *op. cit.*, p. 113.

problems were being addressed by a new generation of manufacturing equipment, “the competition to differentiate products to meet users' rapidly evolving needs had already rekindled.”²³

A respected industry analyst, writing in 1997, estimates that the FPD market grew from \$100 million to \$14 billion from 1980 to 1997.^{24,25} The market was driven first by consumer electronics, then portable computers. In 1997, the next wave of production was expected to include tens of millions of notebook computers, desktop monitors and TVs. The explosive market growth of selected markets is shown in Table 2-1. According to industry observers, it was the market for notebook PC displays that really drove the market take-off. PC manufacturers couldn't get all the displays they needed from the market, much less from a single supplier. In the early 1990's one leading PC maker qualified the products of eight display manufacturers, and led the notebook display standardization charge — along with several other PC manufacturers — so the PC makers could obtain the same displays from multiple FPD manufacturers.²⁶

Table 2-1. Market Growth by Selected FPD Applications

Market	\$M (1997)	\$M (2003)
Portable Computers	\$7,443	\$10,360
Desktop Monitors	\$397	\$7,483
Handheld Computers	\$119	\$715
Camcorder	\$379	\$421
Digital Still Camera	\$131	\$313
GPS (aftermarket)	\$145	\$290
Financial Terminals	\$136	\$255

This growth has continued to be driven by the expanding applications of panels made with the dominant TFT-LCD technology. In addition to flat screens for notebook computers, new applications for these panels keep being developed including desktop computer monitors (displacing traditional cathode ray tube displays), LCD TVs for the consumer television market, small displays for cell phones, digital still cameras, and personal digital assistants, as well as very large format displays such as the electronic billboards that adorn the facades of buildings.

²³ Murtha, et. al., *op. cit.*, p. 113.

²⁴ David E. Mentley, “Market Opportunities for Advanced LCDs,” Stanford Resources, Inc., *1997 Flat Information Displays Conference*.

²⁵ It is assumed that these market value numbers are nominal, not adjusted for inflation. The source (Ibid.) provides no indication.

²⁶ Mark Fihn, personal communication, November 5, 2010. The PC makers developed the Standard Panels Working Group (SPWG) standard. According to the SPWG web site, the organization was formed in May of 1999 by Compaq, Dell Computer, Hewlett-Packard, IBM, and Toshiba for the purpose of establishing mechanical and interface specifications for the displays used in notebook PCs. Widespread adoption of SPWG-compliant panels — encompassing specifications for 13.3", 14.1" and 15.0" displays or approximately 60% of all displays used in notebook PCs — has served to simplify design-in cycle times, to reduce component and manufacturing costs, and to better assure a steady source of supply in a volatile market. SPWG estimates that its adoption has saved the notebook PC industry more than \$100 million in costs annually. The SPWG references the FPDM.

According to one estimate the industry as a whole generated \$62 billion in gross revenues in 2004 with an anticipated yearly growth rate of approximately 40%. Writing in 2005, the analyst predicted that within the next decade the value of industry shipments would come to \$100 to \$200 billion, making it comparable to semiconductors.²⁷ In 2010 the total revenue from the sale of TFT LCDs was approximately \$90 billion.²⁸

While Japanese firms dominated the product markets during the industry's "take off," Korean and Taiwanese firms have rapidly entered, as have firms from Singapore, China, and India. U.S. and European firms, by contrast, appear to be pinning their strategic aspirations on the development of new applications and new technologies, having apparently abandoned the effort to manufacture active-matrix TFT-LCDs in mass quantities. U.S. firms, such as Applied Materials, Corning, Photon Dynamics, and Applied Films Corporation have strong positions in the equipment and materials markets that supply FDP manufacturers. FDP manufacturers spend billions of dollars annually updating fabrication and test equipment.²⁹

2.2 Flat Panel Display Metrology

Display metrology is concerned with the measurement of the optical properties of electronic displays. Display metrology is practiced in order to provide physical data as an objective basis for rating of the visual performance of electronic-display devices; *e.g.*, *luminance* is measured in order to estimate the *brightness* perceived by a human observer. Display metrology and the resulting data are of significant commercial interest and thus often are subject to manipulations. Hence, the stakes for understanding and properly exercising the practice of display metrology can be high.³⁰

In the early phases of the exploding market for FPDs there was a confusion of terms and definitions and measurement approaches. According to a leading industry metrologist, "This confusion is often exploited by marketers by selecting such measurements that are yielding the 'best numbers' for the product data sheet. In line with that mentality of specsmanship (i.e., abuse of technical data to establish putative superiority of one device over another) [an example] is the measurement of contrast in a dark room, yielding

²⁷ John A. Mathews, "Strategy and the Crystal Cycle," *California Management Review*, Vol. 47, No. 2, Winter 2005, pp. 6-32. (Data update provided by John Mathews, personal communication, June 2, 2011.)

²⁸ Estimated for 12 months from September 2009 to August 2010 from data provided by DisplaySearch at http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/resources_paneltrack.asp, November 4, 2010.

²⁹ Mathews, *op. cit.*

³⁰ Michael Becker, "Display Metrology: What Is It (Good for)?" *Information Display*, February 2008 Vol. 24, No. 2, p. 4, 52. Becker observes, "In a 2003 court case (NEC Mitsubishi Display of America vs. ViewSonic Corp., Illinois Federal Court, Case No.: 02 C 08304), for example, NEC Mitsubishi charged that ViewSonic was misleading or confusing customers with the way they specified the contrast of ViewSonic LCD monitors. The case was between competitors but similar cases involving consumer advocacy groups have, over the years, taken manufacturers to task for issues of exaggerated technical claims."

(very) high numbers, especially for emissive displays, but under conditions that do not represent the actual application situation (about 99% of all display application cases are under ambient illumination).”³¹

Display metrologists spend their entire careers pursuing two goals:

- Making the most precise and accurate measurement of light from displays
- Finding the best correlation possible between what they measure and what users of the displays actually see.

This is no simple task. “There are an astounding number of commercial instruments on the market today that even when used as rigorously as possible are not better than $\pm 10\%$ in absolute accuracy. Whether that performance is good enough for the intended application is a real problem with which display metrologists regularly struggle.”³² NIST’s Flat Panel Display Laboratory (FPDL) was established in 1992, attuned to the fact that addressing these “real problems” was a key to the proliferation and growth of FPD applications.

2.3 Establishment of NIST’s Flat Panel Display Laboratory (FPDL)

In the late 1980s and early 1990s the U.S. economic policy community was engaged with concerns about U.S. international competitiveness.³³ A NIST planning report from the period focused on the measurement facets of competitiveness:

At present, U.S. industry is experiencing a major shortfall in the measurement capability needed for competitiveness in electronic products. This document identifies the measurement needs that are most critical to U.S. competitiveness, that would have the highest economic impact if met, and that are the most difficult for the broad range of individual companies to address.³⁴

According to one of its authors, the report is evidence of the institutional context in which NIST’s FPDL was established.³⁵ The National Bureau of Standards (NBS) had recently been reorganized and renamed the National Institute of Standards and Technology (NIST) by the Omnibus Trade and Competitiveness Act of 1988. Two chapters of the report (Chapter 11, Video; and Chapter 12, Electromagnetic Compatibility) focus especially on flat panel displays, a focus explained by:

³¹ Ibid.

³² Stephen Atwood, “You Might Be a Display Metrologist If,” *Information Display*, February 2008 Vol. 24, No. 2, p. 2.

³³ See, for example, R. D. Norton, “Industrial Policy and American Renewal,” *Journal of Economic Literature*, March 1986; and Otis Graham, *Loosing Time: The Industrial Policy Debate*, Harvard University Press, 1992.

³⁴ *Measurements for Competitiveness in Electronics* (NISTIR 4583), U.S. Department of Commerce, National Institute of Standards and Technology, Electronics and Electrical Engineering Laboratory, April 1993.

³⁵ Communication with Herbert Bennett, November 29, 2010.

“The emphasis given in this chapter to flat-panel displays is driven largely by the intense competition already evident in this area. Nations, especially Japan, are investing very large amounts of resources to manufacture flat-panel displays since the markets for products containing displays are expected to be enormous. Japanese companies are investing over \$2.0 billion in flat-panel-display plants costing from \$45 million to \$300 million each for the first stage. Additional stages may bring the total investment to over \$900 million for some individual plants. The realization of the key role that displays play, and the investments that Japan and the U.S. have already made, have produced much interest in display technologies.”

While NIST’s expectations for U.S. industry’s production of flat panel displays never came to fruition (as discussed in section 2.1, today the U.S. share of the worldwide display manufacturing industry is small), this FPDM impact assessment demonstrates that the pay-off from NIST’s focus on U.S. companies that incorporate flat panel displays in their products and services has been significant.

The FPDL was founded in 1992 on NIST’s Gaithersburg, Maryland campus³⁶, under the leadership of Dr. Edward Kelley. Kelly, Paul Boynton, and others, soon demonstrated that industry offered little in the way of standard tests to evaluate the quality of FPD products. Many of the people performing flat panel display measurements were doing it in a manner that would produce erroneous results. The researchers found a situation in which published specifications from one manufacturer's display couldn't be directly compared with the specifications from another manufacturer's display. The FPDL adopted a mission to create a battery of test methods that all manufacturers could use to determine the actual performance of their displays so that the end user could accurately compare flat-panel display performance. The technical situation facing display metrologists at the time has been described as follows:

The two most important performance categories for any display device are contrast and color accuracy. Because of the nature of flat-panel devices, your viewing environment makes a major difference in the perceived contrast range of the display's picture. For years display manufacturers used the "bright room test" to determine a display's contrast under normal room conditions. This test consisted of placing a bank of fluorescent lights that put out 100 Lux of light above the display and then measuring the black and white boxes of a standard checkered display pattern. The difference between the black box and the white box was the contrast ratio, although this test proved to be fundamentally flawed. First, the ambient light level in an average room is well above 100 Lux (closer to 300 to 400 Lux). More importantly, depending on the placement of the light and measuring device, measurements could vary as much as 1,000 percent. Even minute changes in the location of the light, measuring device, and

³⁶ The FPDL was moved to the NIST campus in Boulder, Colorado in 2003.

even the size of the testing room can cause radically differing results, making this test virtually worthless for comparing displays made by different manufacturers, as each company conducted tests in their own unique facility. There had to be a better way.

NIST's Flat Panel Display Lab developed a standard way to measure not only the reflectance of front-panel-display materials, but also a display's contrast under different ambient light levels. The methodology involves using a closed chamber with critically even illumination and a carefully calibrated light level that technicians can accurately reproduce day in and day out. Trained testing personnel can set up a chamber anywhere, and once it's properly calibrated, their tests will correlate with tests performed in other chambers anywhere in the world. This codification of testing procedures forms the backbone of the Flat Panel Display Lab's work.³⁷

At the time, the best of the commercial measurement laboratories (for example, the David Sarnoff Research Center's National Information Display Laboratory (NIDL)), had a number of procedures written out that were self-contained, but they suffered from redundancy. Some of the metrics that became part of the FPDM standard were in common practice in the cathode ray tube (CRT) world and used by the leading laboratories in the U.S. and Japan. But often the documentation for the leading laboratories was sparse. Some related standards, ISO 13406-2 (an ergonomic standard), for example, suffered from insufficient details on the methods and hidden interpretive problems. Old methods were designed for CRT displays, but were being applied to LCDs and other new technologies, resulting in serious measurement errors.

In the context of the VESA Workgroup, NIST experts worked with industry metrologists to remove redundancies and better organize their information. NIST experts participated in an inter-laboratory comparison to verify their metrics. Representatives from the leading commercial laboratories became part of VESA's FPDM Workgroup.

With NIST's expertise, explanations were expanded and warnings were added. NIST contributed rigor and explanation. Over time, the work of the FPDL moved from the complicated modeling required to address basic metrology needs to correcting the many errors in most existing measurement procedures. According to Kelley, "We focused the metrics on lab people making good measurements. ... We pulled it all together and made it robust, reproducible, unambiguous, and solid."³⁸ There were four main tracks to the FPDL's efforts:

- Metrology efforts in support of the FPDM Workgroup
- Stray light management
- Reflection metrology

³⁷ Mike Kahn, "Flat Panel Display Lab," January 2008, <http://www.hometheatermag.com/hookmeup/108flathook>.

³⁸ Communication with Ed Kelley, November 22, 2010.

- Diagnostics.³⁹

FPDL activities attracted visiting scientists from national metrology institutes and governmental laboratories, including the United Kingdom (NPL), South Korea (KRISS), and Brazil (INMETRO). NIST's FPDL experts established a four-day display metrology "short course" to provide scientists and engineers extensive hands-on experience in display metrology. The course attracted over one hundred display professionals from thirteen countries.⁴⁰

2.4 Video Electronics Standards Association (VESA) FPDM Workgroup

2.4.1 VESA

VESA's origins are rooted in the early evolution of the personal computer industry. The phenomenal growth of graphics capabilities for personal computers in the 1980s and the subsequent proliferation of non-compatible products led to the formation of VESA in 1989. The VESA Flat Panel Display Interface (FPDI) Committee was formed in February 1994 to develop a standardized interface between graphics controllers and flat panel displays used in integrated environments such as portable PCs.⁴¹

VESA's first standard allowed computer users to take full advantage of the advanced graphics capabilities offered on the market at that time.

2.4.2 FPDM Workgroup

In April 1995, the VESA FPDI Committee established an initiative to develop voluntary standards for the measurement of flat panel displays and formed the Flat Panel Display Measurement (FPDM) Workgroup. The Workgroup's purpose was to:

- Ensure consistent, relevant display measurements
- Foster display improvements and new developments
- Aid in display system design and procurement.⁴²

The Workgroup was formed at the instigation of FPDI Committee members Joseph Miseli (Sun Microsystems) and Doug Baker (Compaq). Kelley, of NIST's FPDL, assumed the Workgroup chair in 1995, following Dennis Bechis (NIDL), and was the editor of FPDM 1.0 and 2.0.⁴³

The FPDM Workgroup built upon the metrology work of the NIDL and the work of Japan's Electronic Industries Association of Japan (EIAJ). The core of the FPDM is

³⁹ See Appendix B for a breakdown of published papers and presentations by FPDL staff that reflects their focus over the history of the FPDL. In addition to the four main tracks of research noted, FPDL staff conducted FPD metrology tutorials and developed display metrology for specific applications.

⁴⁰ Undated NIST, SID Fellow Award nomination document.

⁴¹ <http://www1.ecs.ru.acad.bg/kp/less/dispalys/VD-site/vesa/ve00005.html>

⁴² <http://www1.ecs.ru.acad.bg/kp/less/dispalys/VD-site/vesa/ve00005.html>

⁴³ Communication with a source who requested anonymity, May 26, 2011.

metrology, the science of measurements, not only what to do but how and why do it a certain way. According to Kelley, “All other standards lacked that element, and we filled the niche.”⁴⁴

As an example of the situation display metrologists faced, and the order and rigor that the VESA FPDM standard provided, FPDL’s former director, recalls the following:

NIDL had a number of procedures written out. They were self-contained, but they suffered from a lot of redundancy We removed the redundancy and organized ... things better. There were common measurements made on CRTs. We even participated in an inter-laboratory comparison with [NIDL] to verify their metrics. All of them became part of the FPDM, I'd guess about 35% of the metrics in the FPDM were in common practice in the CRT world and used by NIDL. Another bunch, probably 15%, was added from the EIAJ. The EIAJ document was very sparse. We added the explanations and warnings. The NIST contribution to all of this was rigor and explanation where needed. We focused the metrics on lab people making good measurements. There was also the ISO 13406-2, an ergonomic standard that suffered from insufficient detail on the methods and “gotchas,” and it was very hard to read. There were a lot of standards on CRTs, some good, like the SAE standards (in part), some bad. We pulled it all together and made it robust, reproducible, unambiguous, and solid.⁴⁵

A representative of an equipment manufacturer that incorporates displays in sophisticated computer systems, similarly recalled:

In the early days of developing a product [specification] it took weeks and weeks of discussion and discovery to figure out how to make measurements, especially for “contentious parameters” such as set-up conditions (emphasized in the FPDM). Part of this discussion was with the customers (for whom the system with the display was being designed) and part was with the display manufacturer. The more contentious the parameter the longer the discovery and negotiation process took. FPDM changed that. It provides a unified ‘buffet’ of measurements and set-up conditions that anyone can use and combine in any way they need but with the underlying metrology clearly established.⁴⁶

VESA’s FPDM avoided compliance language and offered a range of display measures from which manufacturers and users could pick and choose according to their requirements. According to the FPDM 2.0 introduction, “What people do with the results is their own business, but we wanted to make sure that it was measured correctly.”⁴⁷

⁴⁴ Communication with Ed Kelley, November 22, 2010.

⁴⁵ Ibid.

⁴⁶ Communication with an anonymous industry source, April 6, 2011.

⁴⁷ FPDM, Version 2.0, 2001.

In this respect, the FPDM was unique. According to one close participant-observer, “Looking back, in 1992, [NIST’s technical staff] were visionary. The market for the notebook PC and the desktop flat panel display had not exploded (until 1998-2000) but they knew what was needed on the metrology front and they knew what they wanted to do.”⁴⁸

Released initially in 1998 (as FPDM Version 1.0), and re-released in June 2001 by a newly formed Display Metrology Committee of VESA, Version 2.0 incorporated corrections and clarifications and expanded test-item coverage. FPDM 2.0 was most frequently applied to consumer active matrix LCDs such as notebooks, monitors, TVs, etc., but its methods and principles extended across industrial, military/aerospace, and medical applications, regardless of display technology, with only occasional caveats.

⁴⁸ Communication, Mark Fihn, November 5, 2010.

3 Economic Analysis Framework

3.1 Documentary Standards as “Infratechnology”

Quantitatively assessing the economic impact of documentary standards requires their conceptualization in a manner that is conducive to economic analysis, that is, in terms of microeconomic categories and logic of market failures.⁴⁹

A recent NIST publication categorizes documentary standards according to a schema that is familiar to participants in documentary standards development processes. The publication categorizes documentary standards by type (terminology standards, product standards, service standards, data provision standards,) and describes the market functions that the types of standards perform.⁵⁰

Assessing economic impact requires further categorizing these market functions in microeconomic terms: First, what are the economic concepts that capture these market functions? Second, to what extent do markets need non-market assistance (the assistance of standards-making organizations and the organizations, like NIST, that provide the technical basis for standards) in performing these market functions? Both questions are addressed in the literature concerning market failures.⁵¹ A categorization of standards that stresses their *economic function* (rows) is combined with a categorization of documentary standards by *type* (columns) to produce the documentary standard’s economic impact matrix shown in Table 3-1. The nature of the chief *economic benefits* (cells) associated with each documentary standards economic function and type is indicated in the table. Not all types of standard perform all economic functions but some economic functions are performed by all types of standard. Quality and reliability assessment, for example, is an economic function primarily associated with testing standards, so only the intersecting cell identifies the economic benefits associated with testing types of standards. On the

⁴⁹ For a thorough discussion of “market failures” and their causes, see Gregory Tasse, *The Economics of R&D Policy*, Quorum Books, 1997; John Roberts, *The Modern Firm*, Oxford University Press, 2004; and Oliver Williamson, *The Economic Institutions of Capitalism*, Free Press, 1985.

⁵⁰ *The ABCs of Standards*, (NISTIR 7614), August 2009. For example, terminology standards permit parties to a transaction to use a common language; product and service standards establish fitness for use; and process standards help establish the compatibility of products or systems at their points of interconnection.

⁵¹ While a large literature exists addressing problems of market failures, little of it addresses the “nuts and bolts” of performing impact assessments. Sparser still is the literature that addresses market failures as they relate to documentary standards and standards-related activities in a manner that clearly informs the practice of impact assessments. The economic literature useful for evaluation purposes includes, Gregory Tasse, *The Roles and Economic Impacts of Technology Infrastructure*, *mimeo*, March, 2008; “Standardization of Technology-Based Markets,” *Research Policy*, 29, 2000, pp. 587-602; Stephen Martin and John Scott, “The Nature of Innovation Market Failure and the Design of Public Support for Private Innovation,” *Research Policy*, 29, 2000, pp. 437-447; David Leech, Albert Link, and John Scott, *The Economics of a Technology-Based Service Sector*, NIST Planning Report, 98-2, 1998; Gregory Tasse, *The Economics of R&D Policy*, 1997; and Oliver Williamson, *The Economic Institutions of Capitalism*, Free Press, 1985.

other hand, all types of standards are believed to foster variety reduction, so all the intersecting cell in the variety reduction row are associated with the economic benefits of economies of scale for producers and reduced search costs for buyers.

Table 3-1. Documentary Standards Economic Benefit Matrix

Economic Function	Documentary Standards Type				
	Terminology, Service, and Product Standards	Data Standards	Interface Standards	Testing Standards	Harmonized Standards
Provision of measurement-related information	<ul style="list-style-type: none"> • Lower transaction costs • R&D efficiencies • Quality/Process control improvements 	<ul style="list-style-type: none"> • Lower transaction costs • R&D efficiencies • Quality/Process control improvements 		<ul style="list-style-type: none"> • Lower transaction costs • R&D efficiencies • Quality/Process control improvements 	
Compatibility/ Interoperability	<ul style="list-style-type: none"> • Increased innovation at the component level • Optimized system design 		<ul style="list-style-type: none"> • Increased innovation at the component level • Optimized system design 		
Quality/ Reliability Assessment				<ul style="list-style-type: none"> • New basis for price/quality competition • Lower costs and/or higher quality products and services 	
Variety Reduction	<ul style="list-style-type: none"> • Economies of scale • Reduced buyer search cost 	<ul style="list-style-type: none"> • Economies of scale • Reduced buyer search cost 	<ul style="list-style-type: none"> • Economies of scale • Reduced buyer search cost 	<ul style="list-style-type: none"> • Economies of scale • Reduced buyer search cost 	<ul style="list-style-type: none"> • Economies of scale • Reduced buyer search cost

The term “infratechnology” was coined to describe the “technical tools” that are ubiquitous in a high-tech economy and provide substantive foundation for many of the documentary standard types identified in Table 3-1. Infratechnologies include measurement and test methods, standard artifacts (such standard references materials or weights and measures artifacts), scientific and engineering reference databases, process models, and the technical basis for both physical and functional interfaces between the components of systems technologies.⁵²

For infratechnologies to effectively perform their functions, they must be shared. For example, for a buyer and seller to agree that a product conveyed by the seller meets the buyer’s performance specifications, the buyer and the seller must agree on how to measure performance. For a buyer to measure the relative performance of a range of competing sellers, the buyer must have a basis for making “apples-to-apples” comparisons of the competing sellers’ performance claims. To take advantage of the competitive process, the basis for apples-to-apples measurement must be equally

⁵² Tasse, Ibid., 1997.

available to all sellers and buyers. In the jargon of economics, infratechnologies have high “public-good” content because buyers and sellers share the know-how to evaluate products.⁵³

NIST personnel serve at least two important economic functions when they are engaged in the documentary standards development process, an “*honest broker*” function and a “*conduit*” function.

A documentary standard embodying an honest broker function is one in which NIST’s participation serves to reduce the cost of reaching an industry consensus on some facet of a standard because NIST is viewed as committed to the highest standards of metrology and devoid of any proprietary interest. Standards are often regarded as efficiency *reducing* to the extent that standard-making organizations are unduly influenced by a subset of companies trying to co-opt the consensus-making process for their own gain at the expense of other member companies or the consumers of their products. The potential for NIST personnel to play important coordinating and support roles should enhance the efficiency of the standards making process.

In addition to the *honest broker function*, documentary standards in which NIST personnel are involved are presumed to serve as a *conduit* for the effective “traceability” of *international standards* of physical measurement through *national representations* of international standards (maintained by NIST), all the way to the *working standards* of measurement employed in industry. From there, ultimately, documentary standards affect the transactions among buyers, sellers, and competitors. In this “conduit” role, *documentary standards* form a strong “bridge” that connects international agreements about measurement standards to a “local,” product market-specific context. That bridge will be strongest — and NIST’s “conduit function” most effective — where documentary standards are based on the most technically-defensible, widely-recognized infratechnologies.

3.2 An Economic Perspective on the Genesis of a the FPDM

Documentary standards are vehicles for the transmission of “infratechnology,” measurement practices and know-how that must be shared to be useful. If two parties — for example, a buyer and a seller — are going to agree on the measurement criteria by which a product or process will be assessed, they must agree on and share the underlying measurement practices for the assessment to be performed effectively.

⁵³ “Public” in this context refers to the availability of, or access to, the basis for making measurements to confirm performance, *not* to the distinction between social estates or sectors, as when reference is made to public and private sectors. The private sector can provide public goods. See, Harold Demsetz, “The Private Production of Public Goods,” *Journal of Law and Economics*, Vol. 13, October 1970, pp. 293-306. While the private sector can provide public goods like infratechnologies, their provision, as indicated in Figure 1, is regarded as one of the barriers to innovation; a barrier that public-private barrier mitigation strategies — such as consensus-based documentary standards development efforts — are intended to address. So, the public sector often plays a significant role in the provision of goods and services with high “public” content even though, logically speaking, it need not.

Economic logic suggests that where multiple parties must share measurement know-how, the incentive to invest in the development and dissemination of that information will likely confront free-rider problems. In addition, policing problems are likely to arise when complex technologies make the identification of product quality dimensions hard to specify and measure uniformly, all the more when parties act with guile to advance the position of their products at the expense of others who are attempting to come to a multiparty arrangement.⁵⁴ When the number of participants in a business arrangement is small, private negotiations (contracts) can address the free rider problem as well as the measurement specification and policing issues. When the number of parties is large and varied, the cost of developing and policing satisfactory contracts could become prohibitive and some form of collective decision-making (often involving a government institution) may be sought to keep transaction costs within acceptable boundaries.⁵⁵ Standards Development Organizations (SDOs) often arise to address measurement issues such as these.⁵⁶

Requirements for new measurement technologies continuously emerge as product and process technologies develop. To the extent that new product and process technologies emerge mostly from private sector initiatives, the measurement technologies used to demonstrate their performance are initially developed internally and communicated, for example, between organizations within the same firm or between corporate partners engaged in collaborative arrangements. To the extent that private sector firms guard their new product and process developments from competitors, they likely develop and guard the associated measurement technologies. As discussed in section 3.1, measurement technologies (infratechnologies) have the greatest economic impact to society if they are widely disseminated. For many industries, historically, this dissemination was thought to have come about by the gradual change in industry structure. In the case of the FPD industry, the traditional explanation is probably insufficient. Rather, NIST, working with industry through the FPDM Workgroup, played an important role in disseminating FPD infratechnologies.

Traditionally, the distinction between product and process technologies has been important for explaining how the structure of an industry evolves over time. Accordingly, in the early stages of a product life cycle, innovative product features are regarded as more important to buyers of new products than manufacturing process control and cost

⁵⁴ E. F. Kelley, "What Do the Specifications Mean?" *Proceedings of the First Americas Display Engineering and Applications Conference* (ADEAC 2004), Society for Information Display, Ft. Worth, TX, USA, pp. 15-18, October 26, 2004.

⁵⁵ In the context of oligopoly coordination it has been suggested that the difficulty of coordination rises nearly exponentially with the number of parties involved. Unless there is a central coordinator, each firm must tacitly or overtly communicate with every other over matters of concern. The number of two-way communications required is given by the combinatorial expression $N(N-1)/2$. With two participants the number of two-way communications is 1. With six participants it rises to 15. See, F.M Scherer, *Industrial Market Structure and Economic Performance*, 1980, pp.199-200.

⁵⁶ The focus of this report is measurement technology standards. A similar logic applies to other kinds of standards, such as terminological standards, data standards, interface standards, testing standards, and harmonized standards. For a discussion of the various kinds of standards see, *The ABCs of Standards*, (NISTIR 7614), August 2009.

control. In time, when the scale of the industry expands, and competitors enter the market, cost control and process technology come to dominate firms' strategies, they spin off what are now well-controlled internal processes to manufacturing process specialists who compete with other process specialists and drive down process costs. This is one view of how process technology (and undifferentiated measurement infratechnology) comes to be disseminated.^{57,58}

However, this product-process distinction is inadequate for understanding the evolution of the FPD industry and the role of VESA's FPD Workgroup in that process. Rather, a new perspective explicitly emphasizes the central role of measurement know-how, especially in technology-driven industries. This new perspective asserts that enterprises are not free to dis-integrate and re-integrate competitive capabilities on the basis of the maturity of their process technologies if the interface between stages of value-added in an industry is characterized by "unstructured technological dialogue."⁵⁹ According to this perspective, unstructured dialog between stages or elements of the value-added chain must be transformed into "structured dialog" for those value chain elements to be deployed strategically (either as independent spin-offs or as internal specialized or co-specialized assets in support of customers). For structured dialog to occur, three conditions must be met:

- The customer that procures or uses an input must understand and be able to specify to its supplier which attributes or parameters of the product or service must be provided, *and to what tolerances*;
- Metrics for those attributes must exist, and *the technology to measure those attributes must be available, reliable and unambiguous*; and
- The procuring company must understand the interactions or interdependencies between the attributes of what is provided and the performance of the system in which the procurer will use it. *If there is*

⁵⁷ See, G. Stigler, "The Division of Labor is Limited by the Extent of the Market," *The Organization of Industry*, University of Chicago Press, 1968, pp. 129-141.

⁵⁸ Improving on Stigler's conceptualization of how business strategy and industry structure change over the product life cycle, David Teece distinguished between tight and loose "appropriability regimens" (that make it easier or harder to control the leakage of product innovations) and emphasized how tacit product and process know-how make it hard for innovators to communicate with collaborators. As an alternative to the view that process technologies are typically gotten under control and spun off, Teece called attention to the role that deploying specialized and co-specialized process technology assets (such as specialized repair facilities) could have on profitability once innovative product designs were stabilized. (See, D. Teece, "Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy," *Research Policy*, 15 (1986) 285-305.) Teece envisioned a result similar to that envisioned by Stigler: "Islands of specialized capital ... [in a] sea of general purpose manufacturing equipment." Whether these specialized assets include measurement technology on Teece's account is hard to say. How tightly measurement technologies are tied to the product and process improvements they authenticate is an issue to be discussed momentarily.

⁵⁹ Clayton M. Christensen, Matt Verlinden, and George Westerman, "Disruption, Disintegration, and the Dissipation of Differentiability," *Industrial and Corporate Change*, Vol. 11, No. 5, 2002, pp. 955-993.

any variation in what is provided, the procurer needs to understand how, when and why it will affect the performance of the system.”
(Emphasis added.)⁶⁰

The traditional distinction between product and process technology is insufficient for understanding this formulation. Only by introducing measurement technology (infratechnology) as a separate and essential complement to the traditional product-process distinction can unstructured technological dialog be transformed into structured technological dialog. This three-part categorization of technology — product-measurement-process⁶¹ — is necessary for understanding the genesis of the FPD in the context of the fast-paced evolution of the FPD industry in which product, measurement, and process technology development were tightly bound.

Some analysts claim that the FPD industry is exemplary of new globally competitive, knowledge-driven manufacturing industry. In such industries, price competition occurs before the technology settles down to a dominant design so that companies face relentless pressures to reduce costs, while investments in R&D and updating of plant, equipment, materials, and processes continue to rise.⁶² An additional attribute of this early phase of a technology’s life cycle is the extra costs incurred in assuring customers that the performance of competing designs is being articulated and measured accurately. Otherwise, the additional substantial transaction costs can create a competitive disadvantage.

In the FPD industry the fast pace of dialectical change among product, measurement, and process technologies might not have allowed the vertical dis-integration process to transpire as expected because the “feedback from a continuous person-to-person and person-to-equipment interaction at the operational level play[ed] a vital role in accumulating and transmitting knowledge for new equipment generations.”⁶³ Making the point somewhat differently, and retrospectively, computer notebook industry participants observed,

In the early years, standards were sorely needed [but unavailable] to reconcile the emerging requirements for new display applications with new design specifications. This was largely accomplished by countless proprietary requirements specs exchanged between panel makers and the notebook contract manufacturers. Early panel specifications referenced VESA timing standards (originally established for CRT monitors) and Japanese optical measurement methods (composed [merely] of a page or two in the back of the spec). There was no urgency to optimize relationships between price, volume, lead time, quality, and

⁶⁰ Ibid., p. 958

⁶¹ “Infratechnology” could be substituted for “measurement” in this triad but the emphasis here is on the transformation from “nascent infratechnology” (proprietary measurement technology) to “effective infratechnology” (commonly used (i.e., standardized) measurement infratechnology).

⁶² Thomas Murtha, Stefanie Lenway, and Jeffery Hart, [hereafter, Murtha, et. al.] *Managing New Industry Creation: Global Knowledge Formation and Entrepreneurship in High Technology*, 2001, pp. 8-9.

⁶³ Murtha, et. al., *op. cit.*, p.113.

interchangeability; ODM-Supplier partners were just trying to get the flat panel technology to work, fit in the lid, and not look too bad – all while keeping up with increasing volume demands.

Today, industry standards such as the VESA Notebook Standard Panel standards (defining timing, electrical interface, and mechanical outline) and VESA Flat Panel Display Measurement standard (defining measurement methods) are critical to the display industry *because they enable discussion of display electrical, optical, and mechanical attributes in a common language up and down the food chain.* [Emphasis added.] These standards played key roles in quantifying the current definition of panel quality.^{64,65}

As late as 2008 analysts were observing that a high percentage of “in-house” value added (above 80%) still dominated FPD manufacturers and OEMs in some important sectors.”⁶⁶ So the traditional “process specialization” explanations of industry evolution and growth didn’t explain the dynamics of the FPD industry. Rather, the “discussion” of technical attributes enabled by the FPD is a clear example of *unstructured technological dialog being transformed into structured technological dialog*. In the FPD industry it wasn’t vertical dis-integration of the industry, and process specialization, that opened up opportunities for industry growth and development. Other forces were at work that centrally involved measurement technology: the explosion of FPD applications, on the one hand, and the creation of NIST’s FPD and the SDO consensus-based standards-making process on the other hand.

First, the range of industries finding applications for relatively large FPDs was expanding and these were industries into which the FPD manufacturers had not generally integrated forward. Industry analysts contend that the companies holding the preponderance of market share for products that incorporated the most advanced displays were not Japanese. Three of the global top-four notebook sellers (typically Toshiba, IBM, Dell, and Compaq) were consistently U.S.-based. Once the notebook market emerged, in the U.S. especially, it evolved rapidly. That evolution was driven, on the demand side, by the increasing size and sophistication of a mobile workforce demanding laptops, rapid

⁶⁴ P.A. Downen, S. Peana, J. Yasukawa, E. Munteanu, and J. Conway [hereafter, Downen, et. al.], “Meeting the Product Qualification Needs of a Rapidly Growing Industry,” ADEAC 05/Society for Information Display, 2005.

⁶⁵ According to a participant in the development of the Standard Panels Working Group (SPWG) standard, the SPWG had already developed the basis for the VESA Notebook standard and the VESA Notebook standard, as such, was not as widely adopted as the SPWG standard. Personal communication with Mark Fihn, November 11, 2010.

⁶⁶ Brian Chen, “2008 LCD TV Panel Makers’ Production Plan and Panel Roadmap,” *Display Search*, January 16, 2008, especially, “LCD TV Outsourcing Status & Future Outlook,” p. 47, and “LCD TV Brand In-House vs. OEM,” p. 48.

progress in personal computing technology, the emergence of the World Wide Web, the spread of high-speed Internet access, and the rapid advancement of the digital infrastructure.⁶⁷

What was nascent in the early 1990s was clear by 2005. By then, the flat panel display industry served a wide variety of applications with display diagonal sizes from 1 inch to 80 inches. The five largest shares, by revenue, were desktop monitors (31%), mobile telephones (18%), LCD televisions (14%), notebook PCs (12%), personal digital assistants (7%). Other significant applications included pagers, MP3 players, home appliances, games and digital cameras, calculators, automotive applications, and toys.⁶⁸ Many professional and consumer products now depend on electronic displays.

Looking back, a market participant made the following observation:

[T]he changing notebook market has steadily shifted ownership of the definition of display quality from the original design manufacturer (ODM) – read as “notebook maker” – *to the collective customer* comprised of corporate, governmental, academic, and private organizations as well as individual consumers. (Emphasis added.)⁶⁹

Driving that shift in ownership of the definition of display quality were demand-side factors that came into focus over a decade:

For the flat panel display industry, the notebook computer has been the undisputed king of the killer applications having fueled research and development that is now reemerging in all mobile devices, flat panel monitors, and LCD TVs. ... The notebook flat panel display has become a commodity item characterized by high volume production, a customer-driven quality threshold, and more price than performance discrimination. One leading notebook maker, for example, utilizes eight different AMLCD panel vendors in Korea, Japan, and Taiwan to feed their notebook production demand.

⁶⁷ Murtha, et. al., *op. cit.*, p. 4.

⁶⁸ David Hsieh, “Flat Panel Display Market Outlook,” *Display Search Company*, November 5, 2005, p. 8.

⁶⁹ Phil Downen, “A Closer Look at Flat Panel-Display Measurement Standards and Trends.” *Information Display*, No. 1, 2006. Close market observers differ on the specifics. Mark Fihn, for example, argues that until about 1990, display quality for the notebook market was defined primarily by the LCD maker; only from 1990 until about 2000 was it defined primarily by the notebook OEM; and more recently it has been primarily defined by the notebook manufacturer (Quanta, Compal, Wistron, Pegatron, etc), who built the vast majority of notebooks for their notebook OEM customers. Personal communication with Mark Fihn, November 18, 2010. Regardless of these specifics, Downen’s “collective consumer” emphasizes the “demand side” of the dialectical relationship between the supplier and the buyer wherever it occurs in the supply chain. The argument in this section is that the possibility of such a shift was enabled by what Christenson calls “structured dialog”; that the FPDM reflects the three conditions that enabled structured dialog to occur; and that the role of NIST’s FPD (as “honest broker” and “conduit” of international standards of display metrology) was fundamental to that process.

Commodity status, however, in no way guarantees that the process of designing, producing, integrating and delivering flat panel display products is optimized. The panel supply chain alone is complex and fraught with challenges for ODMs (*original design manufacturer – read as “notebook maker”*) and panel maker alike. Concerns over panel costs and time to market are just now supplanting yesterday’s worries about viewing angle, color gamut, response time, form-fit-function, and reliability. Still, managing panel quality cannot be taken for granted; it requires a portable and scalable solution that is owned by both the ODM and display maker.⁷⁰

The supply side of the flat panel market was expanding rapidly as well as, first, Korean companies, LG and Samsung, joined the Japanese as key global suppliers in 1993, and then Taiwanese companies, Acer Display Technology (ADT – now AUO), Chi Mei Optoelectronics (CMO), Chunghwa Picture Tubes (CPT), HannStar, and Quanta Display Incorporated (QDI), joined the ranks of global suppliers from 1998 to 2001.⁷¹

The second major enabler of the FPD industry take-off was that NIST’s FPD came on the scene. Its participation in the VESA FPD Workgroup allowed all three conditions for structured dialog to be fulfilled. Arguably, before NIST set up the FPD:

- The “customer that procures” was unable to specify and compare parameters at a reasonable cost
- “Technology to measure” was unavailable, unreliable, and ambiguous; and
- “Variation in what was provided” by various FPD producers limited the procurers’ abilities to understand interdependencies between attributes and performance.

As long as these measurement issues were unresolved, attempts to reach consensus in so technically challenging and complicated a field would be bogged down in “specsmanship”: “reporting a measured value that is deliberately intended to mislead or where the display is measured in a configuration in which it would never be used but provides better reporting values. ... to hide a deficiency for competitive purposes.”⁷²

To summarize, the “take off” of the flat panel industry that followed the initial development of the industry’s 14-inch notebook screen “killer app,” led to a rapid expansion of applications in industries into which, by and large, FPD manufacturers had not integrated. The measurement technology required by FPD applications developers could not be liberated from its proprietary sources within the integrated FPD manufacturers — where, due to the fast-paced, dialectical nature of product-process-

⁷⁰ Downen, et. al., *op. cit.*, 2005

⁷¹ *Ibid.*

⁷² E. F. Kelley, “What Do the Specifications Mean?” Proceedings of the First Americas Display Engineering and Applications Conference (ADEAC 2004), Society for Information Display, Ft. Worth, TX, USA, pp. 15-18, October 26, 2004.

measurement technology development patterns it had the quality of “unstructured technological dialogue” — until it could be translated into the “structured dialog” that would allow FPD users to compare FPD parameters at a reasonable cost, implement unambiguous measurements, and understand the relationship between the FPDs’ attributes and the performance of the users’ applications. NIST’s FPDL proved essential to achieving the transition as reflected in VESA’s FPDM standard.

3.3 The Economic Implications of FPDM Workgroup Inputs and Outputs

The FPDM was initially created to solve a set of problems associated with the characterization, specification, qualification, and assessment of flat panel displays for a broad range of uses that could not be adequately addressed by a range of existing related standards. The information required for the resolution of these problems was a primary output of the Video Electronics Standards Association (VESA) FPDM Workgroup.⁷³ This primary output took at least two forms: the codified measurement infratechnology represented by the FPDM itself, on the one hand, and metrology equipment designs by NIST’s FPDL, largely in support of the FPDM Workgroup on the other hand.

Also, due in large part to NIST’s involvement in the FPDM Workgroup, the standard development process was more effective and efficient than it otherwise would have been. This was a secondary output of the FPDM Workgroup configuration. This “process efficiency” took two forms: the time it took for the FPDM Workgroup and VESA (as an SDO) to reach consensus was significantly reduced; and other SDO’s process times were reduced to the extent that the FPDM could be incorporated into their documentary standards. These SDO process efficiencies are a secondary output of the configuration of the FPDM Workgroup.

Finally, as the discussion in section 3.3 indicates, the FPDM also represented the culmination of a process that played an important part in the take-off of the FPD industry and the utilization of FPDs in a wide range of applications. The FPDM represented the transformation from “unstructured technological dialogue” to a “structured dialog” between manufacturers and users. This was a significant, tertiary output of the FPDM Workgroup’s efforts. This last aspect of the FPDM Workgroup’s efforts was thoroughly discussed in section 2.2 above. The following four sub-sections (3.4.1-3.4.4) further describe the primary and secondary outputs of the FPDM Workgroups efforts.

3.3.1 FPDM: Codified Measurement Know-How

The FPDM is a document consisting of approximately 300 pages of measurement procedures, discussions of measurement problems and difficult concepts, an approach and short template for reporting measurement results, and conventions for naming and reporting parameters that characterize flat panel screens. Flat panel measurement

⁷³ In 2007, the VESA FPDM Workgroup was reorganized into the International Committee on Display Metrology (ICDM) within the Society for Information Display (SID), a professional organization representing technical and business disciplines that relate to display research, design, manufacturing, applications, marketing, and sales.

technology is codified and transferred to users of the document. The *first order utility* of the FPDM is associated with the metrology cost saving experienced by manufacturers and integrators of flat panel displays.

Prior to the development of FPDM, a producer or buyer of flat panel displays (FPDs) would consult any (or all) of a number of existing standards (depending on the specific application)— ISO 9241 (Parts 3, 7, 8) and ISO 13406 (draft 2); ANSI HSF-100 (1988) and IT7.215 (1992); EIA TEB (27) and TEP (105); VESA Display Specifications and Test Procedures (for CRTs); NIDL’s Procedures for Evaluation and Reporting the Capabilities of High Performance Display Monitors for Imagery Applications; SAE ARP 1782 and ARP 4260; MRP 1990:8 (1990:10);USAF AFGS 87213A; and IEC SC 47C.^{74,75} Utilizing any or all of these non-FPDM standards presented the following challenges for buyers and suppliers of specific FPDs:

- Alternative standards are “requirements based” not metrology based. In other words, they describe what the FPD is to do, not how it is to be tested or whether it succeeds or not.⁷⁶
- Alternative assorted standards were not coordinated so that it would take time to figure out how they were/were not aligned for any specific purpose.
- At best they provided a partial solution (perhaps 60%) to the characterization, specification, or qualification task and, therefore, required the buyer or supplier to develop consolidated and integrated proprietary specifications/qualifications, a very time-consuming process without FPDM.
- In many cases, metrology was specified, but as the writers were not metrology experts, the methods were inadequate; however, few were aware of the inadequacy.
- Addressed old technology (CRTs) and assumed measurement techniques and procedures transferred well to new technologies (e.g., Liquid Crystal Displays, LCDs) – which proved an erroneous assumption.

According to NIST researchers, the quality of FPD metrology was extremely low when the project was launched. The extent of low product quality, product failure, and rework, while unknown, was most likely substantial.⁷⁷

⁷⁴ See, Edward F. Kelley, George R. Jones, Paul A. Boynton, Michael D. Grote, and Dennis J. Bechis. ”A Survey of the Components of Display Measurement Standards,” *Journal of the Society for Information Display*, Vol. 3, No. 4, December 1995, pp. 219-222.

⁷⁵ ISO – International Standards Organization, ANSI – American National Standards Institute, EIA – Electronic Industries Association, EC – International Electrotechnical Commission, SAE – Society of Automotive Engineers, MRP – Swedish National Board of Measurement and Testing, NIDL - National Information Display Laboratory (a private sector laboratory associated with Sarnoff Laboratories), USAF – United States Air Force.

⁷⁶ Procurement standards and product-acceptance standards are not substitutes..

An anecdote provided by an industry participant in the early development of the FPDM captures a primary purpose of this documentary standards activity:

In the early days of developing a product specification, it took weeks and weeks of discussion and discovery to figure out how to make measurements, especially for ‘contentious parameters’ such as ‘set up conditions’ (on which the FPDM focuses — See FPDM 2.0, section 301). Part of this discussion is ongoing discussions with either the customer — for whom the display was being made — or the display manufacturer. The more contentious the parameter the longer the discovery and negotiations process took. FPDM changed that. It provides a unified ‘buffet’ of measurements and set up conditions that anyone can use and combine in any way they need but with the underlying metrology clearly established.

The utility of the FPDM changes subtly depending on a firm’s position in the industry value chain (discussed in section 3.5 below). The *FPDM is used by original equipment manufacturers (OEMs)* — providers of systems or subsystems that incorporate FPDs — when the OEMs have a requirement that needs to be specified in a subcontract. They also employ the FPDM as the basis for qualifying competing displays to ensure that the displays specified for use in their products are neither over- or under-specified (both of which entail unwanted costs). *Display and display component manufacturers use FPDM* to characterize their products and to specify their performance unambiguously. *For optical measurement equipment makers*, the FPDM has been a valuable roadmap for R&D activities over the past 10 years. In the words of one such manufacturer, “the structure, clarity, and pragmatism of the standard has served all of us in the equipment business by defining a set of meaningful measurements (with back-up discussions on methodology and metrology) that could be implemented with practical and robust solutions. ... We’ve promulgated the standard in our sales discussions with panel makers, brand name leaders, [display manufacturers], and component makers.” The FPDM has also helped equipment manufacturers to explain instrument limitations and good metrology practices to customers.^{78,79}

3.3.2 FPDM-Related Metrology Equipment Design

In support of the FPDM Workgroup, NIST researchers also developed and, through professional publications, disseminated the design of several items used in the process of FPD measurement, including:

⁷⁷ P. A. Boynton and E. F. Kelley, "Measuring the Contrast Ratio of Displays: It's Not Trivial." *Information Display*, Vol. 12, No. 11, pp. 24-27, November 1996; and G. Jones, E. Kelley, T. Germer, "Specular and Diffuse Reflection Measurements of Electronic Displays," *Society for Information Display International Symposium Digest of Technical Papers*, Vol. 27, San Diego, CA, pp. 203-206, May 12-17, 1996.

⁷⁸ Personal communication with Paul Boynton (NIST), April 18, 2010.

⁷⁹ In addition to the projects undertaken in support of the FPDM Workgroup, NIST conducted metrology projects focused on specific applications, such as projection displays, medical displays, first-responder imaging cameras, micro-displays, and sunlight readability. These projects will inform the next generation display measurement standard to be published by the SID’s ICDM.

- Stray-Light Frustum
- Stray-Light Elimination Tube (SLET)
- Sampling Sphere, and
- Test Patterns.

A *stray-light frustum* is a specially designed, three-dimensional black plastic cone with the apex cut off, used to make accurate measurements of luminance by reducing glare effects during display testing. The frustum fits within a *stray-light elimination tube (SLET)*, a device that measures luminance by rejecting stray-light corruption even in well-lit rooms.⁸⁰ A *sampling sphere* (or integrating sphere) is a device that allows the power of an optical source to be accurately measured irrespective of the direction of the source.⁸¹ Finally, *test patterns* are image patterns with features of various sizes that serve in place of image artifacts. Some pattern features are much larger (and thus easier to measure) than typical noise features, others scaling down to small clusters of pixels. The larger pattern features are easier to measure and errors that appear when measuring larger features are likely to be even worse with smaller features. With a range of sizes of features, it can be determined how measurement errors scale with feature size.⁸²

3.3.3 SDO Process Efficiencies

The FPDM Workgroup developed a set of criteria for assessing the quality of a documentary standard. These criteria are identified in Table 3-2, The FPDM strove to meet these criteria which were considered to be an extremely high hurdle of quality.

Table 3-2. Quality Dimensions for Documentary Standards

Feature	Definition
<i>Reproducible</i>	Everyone can get the same results on the same display using appropriate instrumentation.
<i>Robust</i>	Insensitive to small changes in the measurement apparatus that will affect the ease with which reproducibility is attained.
<i>Unambiguous</i>	The method is clearly stated and easily understood. Important details that are required for success are not left out.
<i>Extensible</i>	Applicable to as many different technologies as possible permitting inter-comparisons of technologies.
<i>Distinct</i>	The name of a measurement method must be chosen so that it is not confused with another metric.
<i>Honest</i>	The measurement method is not devised to hide an obvious deficiency; redefining familiar terms to cloak a problem.
<i>Accommodating</i>	Enables as broad a range of apparatus as possible.

⁸⁰ John Roberts and Edward Kelley, “Measurements of Static Noise in Display Images,” *Flat Panel Display Technology and Display Metrology II*, Edward Kelley and Tolis Voutsas, Editors, *Proceedings of SPIE Vol. 4295* (2001).

⁸¹ *Encyclopedia of Laser Physics and Technology*, http://www.rp-photonics.com/integrating_spheres.html, May 29, 2011.

⁸² Roberts and Kelley, *Op. Cit.*

Table 3.2, continued

Feature	Definition
<i>Accessible</i>	Requiring the use of highly specialized, or otherwise arcane, apparatus or methods would be avoided unless it is necessary (e.g., for people who influence written standards in order to sell their apparatus when it is not necessary to do so).
<i>Simple</i>	Procedures should be made as uncomplicated as possible, avoiding deliberate obscuration from elitism or exploitation (e.g., deliberately making the standard so difficult to use that only a few experts can use it).
<i>Meaningful</i>	Properly captures the visual experience for task and environment. Measuring what the eye appreciates should not be sacrificed for some related esoteric measurement method of limited use.

The FPDM Workgroup produced a standard that conformed to these exacting dimensions of quality, and, because they employed NIST’s special technical expertise in compiling industry technical input, the Workgroup avoided the “specsmanship” that presumably slows the process of standards development. (See section 2.2 above.) NIST’s expertise was used to make technical corrections to submissions from other FPDM workgroup members. NIST staff analyzed, tested, reviewed, composed, and edited the FPDM drafts under the auspices of NIST’s Flat Panel Display Laboratory.⁸³

In addition to addressing problems concerning the characterization, specification, qualification, and assessment of FPDs for display manufacturers, their suppliers, and their users, *the FPDM was also used as source language for documentary standards being developed by other standards organizations concerned with related equipment. In other cases, the FPDM was referenced by other standards.*⁸⁴ This diffusion of FPDM measurement technology represents another FPDM Workgroup outcome, one that did for other standards organizations what it did for display manufacturers and their value chain participants. In the words of an industry expert, “No other [similar] standard was so profound; so wide-ranging.”^{85,86}

⁸³ These corrections could be simple technical errors or they could be the result of “specsmanship.” See, E. F. Kelley, “Understanding Specsmanship,” 2007 Display Applications Conference, Society for Information Display, Invited Paper 7.1, San Francisco, CA, October 23-25, 2007.

⁸⁴ ISO, IEC, SAE, ITU all reference or use material from the FPDM. Personal communication with Paul Boynton, May 18, 2010.

⁸⁵ Communication with a respected industry expert wishing to remain anonymous, April 6, 2010.

⁸⁶ The *Softcopy Exploitation Display Hardware Performance Standard (SEDHPS), Version 2.1* (28 August 2006), is an example of a standard that references FPDMS. This standard, used across Federal Agencies, is published by the National-Geospatial Intelligence Agency (NGA), Image Quality and Utility (IQ&U) Program. When the need arises, a manufacturer responsible for providing equipment to a Federal agency will refer to this standard in its subcontracts. Another example of this documentary standard diffusion function can be found in the medical display community. According to an FDA representative, the FPDMS directly affected recommendations from the AAPM (a professional organization) and is incorporated as a reference in the IEC Standard Group on Medical Image Display (TC62BWG36).

3.4 Affected Organizations: Industry Structure

The FPDM Workgroup’s outputs effected outcomes across the tiers of the FPD industry. Figure 3-1 depicts the structure of the FPD industry value chain showing examples of producers and consumers within the tiers.⁸⁷

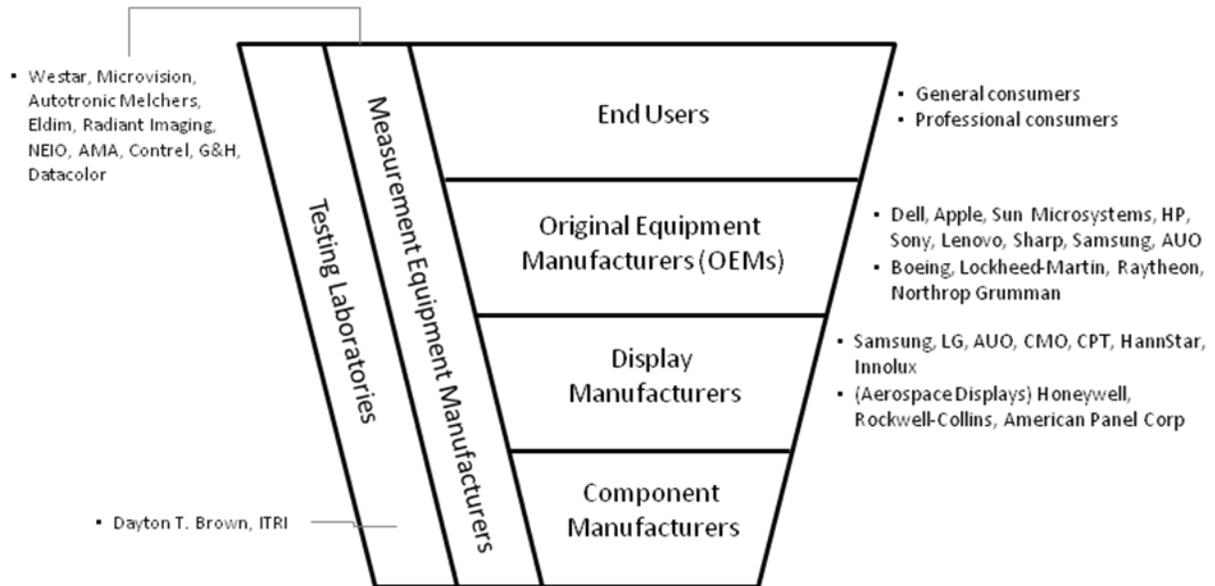


Figure 3-1. Flat Panel Display Industry Value Chain

The first-order beneficiaries of the FPDM are likely to be the measurement equipment manufacturers and testing laboratories (both vendor testing laboratories as well as testing capabilities internal to, especially, display manufacturers, and OEMs).⁸⁸ The ubiquity of metrology equipment and testing services is depicted as the vertical elements to the left in Figure 3-1. For example, the notebook PC OEMs that drove the take-off of the FPD industry in the mid-1990s, discussed in section 2.1 above, maintained sophisticated internal testing laboratories that scrambled to qualify multiple display vendors to meet rapidly rising demand. Similarly today, sophisticated displays for national security-related users employ sophisticated internal capabilities to specify and qualify vendors of high-quality FPDs.

⁸⁷ “Component manufacturers” are shown for the sake of completeness. Interviews with FPD industry representatives suggest that the FPDM has little direct utility for component manufacturers.

⁸⁸ These industry segments themselves may exhibit a microstructure but this information could not be ascertained from the survey conducted for this assessment nor does it appear available from available market intelligence studies.

The scale and shape of testing equipment and services, itself a superset of the smaller market for metrology equipment and services, is hard to ascertain. For 2009-2010, an estimate of TFT-LCD display manufacturers' revenues was \$90 billion worldwide.⁸⁹

A respected market intelligence analyst estimates that for the last several years the total market for TFT-LCD manufacturing equipment market has fluctuated around \$8-10 billion annually. Analysts say that "yield management services" account for less than ten percent of that, and perhaps one percent of that could be allocated to testing and metrology. This rule-of-thumb estimate, coupled with several market niche estimates received from survey respondents, suggest that the current market for FPD metrology-related equipment and services could be in the neighborhood of \$10 million annually.⁹⁰

⁸⁹ http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/resources_paneltrack.asp, November 4, 2010.

⁹⁰ Communication with Charles Annis, *DisplaySearch, Inc.*, December 10, 2010.

4 Assessment Framework and Approach

4.1 Expected Outcomes

Ideally, an impact assessment would be able to enumerate and estimate all the facets of the events in question. As discussed briefly in section 3.2 above, economists have traditionally distinguished between product and process technologies and fashioned the conceptualization of economic impact accordingly.⁹¹ Economic impact assessments conducted for NIST have tended to treat the events or technologies assessed as process technologies, conceptualizing their impact as reductions in the costs of production. The benefits of the technology to users of a product that has higher quality or a new feature are not usually assessed quantitatively.

For this assessment it was originally intended that benefits to users of products with improved features and higher quality due to the availability of the FPDM *would* be estimated and an approach to collecting relevant data was developed. It was hypothesized that higher quality FPDs would increase some customers' *willingness to pay* and the ratio of the price the typical customer would be willing to pay to the actual price of the product (under different counterfactual scenarios) could be estimated by knowledgeable product producers.

In addition, during the course of conducting background research for this assessment it became apparent that the FPD market “take off” of the mid-1990s (discussed in section 3.2) was significantly enabled by the codification of measurement know-how represented in the FPDM — a precondition for the industry’s transition from unstructured to structured technological dialog. This too was a hypothesized outcome of the FPDM Workgroup’s efforts but it was developed too late in the project to be quantitatively assessed.

On the basis of initial interviews with industry representatives, Table 4-1 characterizes hypothesized *sources of cost-reduction benefits* that accrue to firms from the utilization of FPDM across the product life cycle and how the locus of these benefits may vary by industry value chain tier. The columns indicate the major functions metrology serves in the product innovation and commercialization process.

⁹¹ M. Trajtenberg, *Economic Analysis of Product Innovation*, Harvard University Press, 1990, especially pp. 14-16 and pp. 35-40; A. Link and J. Scott, *Public Goods, Public Gains*, Oxford University Press, 2011.

Table 4-1. Sources of Cost-Reduction Benefits from FPDM

Sources by Industry Tier	Product Life Cycle			Complaint Adjustment & Allowances	
	R&D	Qualification Test	Production *		Acceptance Test
FPD End User ¹				X	
OEM ²	X	X	X	X	X
Third Party Test Laboratories	X	X		X	X
FPD Manufacturers	X	X	X	X	X
FPD Measurement Equipment Manufacturers	X		X		X

* Includes costs related to scrap, rework, retest, re-inspection, warranty field engineering, field failure, returned material.

1. *FPD End Users* include general consumers and “pro-sumers” (professional consumers) of “high-end” display-centered equipment, such as medical diagnosis equipment, geospatial data analysis equipment, and military equipment.
2. *OEMs (Original Equipment Manufacturers)* include manufacturers of TVs, computers of most sizes, and integrators equipment systems and subsystems (e.g., medical imaging equipment, geospatial analysis equipment and military equipment system integrators and subsystems manufacturers). Equipment *not covered* includes front-projection displays, micro-displays (including head-mounted displays), and 3-D displays (including stereoscopic, holographic, and volumetric).

It was also expected that the transfer of FPD measurement-related device designs —stray light frustum, stray light elimination tube, sampling sphere, and test patterns — were developed and transferred more efficiently and effectively than they would have been if designed by the companies themselves or designed and transferred by conventional commercial means.

Finally, it was posited that the SDO consensus-making process was made more efficient due to the fact that the composition of the FPDM Workgroup included NIST’s FPDL staff and that the FPDM documentary standard itself was of a higher quality than similar standards due to NIST’s participation.

4.2 Barriers to Innovation

From an economic perspective, efforts at private collaboration and public-private collaboration arise from barriers to innovation. In the case of the FPDM Workgroup’s objectives, a number of such barriers were hypothesized. The FPDM Workgroup’s outputs are believed to have mitigated those barriers and an economic impact assessment of the value of the outputs to industry would reflect the net benefits to society of the FPDM Workgroup’s outputs (described in section 3.3 above).

The primary barrier to innovation in measurement technology arises from the nature of metrology itself. The costs of metrology are high, not least because it is painstakingly exact and the resources required to develop it are highly specialized. The more widely measurement technologies and techniques are shared, the lower the per-unit measurement cost and the broader the market of suppliers who can compete and be assessed on the

basis of “apples-to-apples” product quality comparisons. While this is optimal from the buyer perspective, it can be seen as less than ideal from the perspective of individual suppliers seeking increased market power and, perhaps, status as a *de facto* standard. Proprietary measurement techniques can confer market advantage but at the same time limit the extent to which the measurement techniques and results are shared. It was hypothesized that:

- VESA FPDM Workgroup was formed to address barriers to more open collaboration in terms of shared display quality and performance measurement as the industry evolved;
- The primary form of the barriers-mitigating output is the measurement know-how codified in FPDM-1 and FPDM-2 (that, following Christenson, cited above, enabled the transformation of the quality of FPD measurement practices from unstructured technological dialog to structured technological dialog);
- The types and extent of the barriers differ by industry tier and product life cycle stage; and
- Cumulatively the mitigation of these barriers produce benefits associated with the FPDM Workgroup’s outputs.

In addition, other barriers-mitigation would include:

- The transferred metrology software and hardware designs developed by NIST as a member of the FPDM Workgroup, that some firms have neither the in house resources to design or assess;
- The educational/training workshops made available to industry as a result of NIST’s membership on the FPDM Workgroup, like the embodied software and hardware artifacts, is valued in terms of the cost to industry of developing and conveying similar material.

Some industry representatives claimed that they did not have the specialized expertise to develop or assess the metrology software and hardware designs developed by NIST, but, even if they had, assuring the wide utilization of these artifacts would be difficult in the absence of NIST’s reputation for the highest standards of impartiality. Similarly, regarding the FPDM Workgroup’s educational/training output, given the “thin market” for this type of highly specialized, practical, and applied display measurement know-how, it seemed unlikely that a private organization would have developed such a curriculum, or that normal academic institutions would develop courses to fill such a narrow educational niche.

Finally, it seems likely that information asymmetries among the competitors and rivals that form SDOs drive the costs associated with consensus formation (part of which are due to what has been described above as “specsmanship”) and that NIST’s “honest broker” role dramatically reduced those barriers. Once the FPD metrology was codified in FPDM the barriers to transferring that measurement know-how to related SDOs

(barriers presumably similar to those of the originating organization (VESA)) were no doubt reduced and secondary SDO process efficiencies would accrue to the adopting SDO's.

4.3 Comparison Scenario

In general, the benefits of the FPDM Workgroup outputs are assessed using a counterfactual technique, posing the question, “How would industry events have unfolded in the absence of VESA’s FPDM Workgroup?”⁹² There are at least two ways to formulate a counterfactual question in this case. First, it might be hypothesized that in the absence of VESA’s FPDM Workgroup an alternative organization would have risen to the occasion and the economic benefits attributable to the FPDM Workgroup are weighed against the relative costs of the alternative SDO. This assessment *does not* formulate the issue that way. Rather it asserts that the industry *would not have developed an alternative to FPDM* and that industry would have borne higher costs, and, perhaps, would have expanded less rapidly, in the absence of the FPDM. Before explaining the rationale for this approach to constructing the comparison scenario, a brief description of the *evaluation method* is in order.

Within the context of comparative evaluation scenarios, there are essentially three different evaluation methods that can employ the counterfactual technique. The evaluation method employed for this assessment is a variation of the “traditional method” (also known as the “Griliches/Mansfield method”).⁹³ It estimates the benefits and costs that accrue to innovators and the users of the innovation; sums the net benefits (benefits minus costs) across all beneficiaries; and reports the “social rate of return” where “social” refers to the sum of all the beneficiaries — those who invested in the underlying innovation as well as those who benefited from the innovation without making investments (so-called “free-riders”). When the “traditional evaluation method” is used to evaluate *public* expenditures on R&D projects, for example, the social rate of return is implicitly compared to private rates of return to justify the government investment role and it is assumed that the private sector would not have undertaken the project in question. In the FPDM impact assessment, private collective (SDO) expenditures *plus* public expenditures are being assessed by posing a variation of the traditional evaluation question: “What costs and benefits accrue from the *combined resources* of the public and private organization and what was the economic significance of the public sector contribution?”

To answer this question in the most straightforward manner, it is asserted that absent NIST’s involvement, the industry would not have developed a true alternative to FPDM

⁹² To avoid confusion with the discussion of a “counterfactual evaluation *method*” discussed below, the word “technique” is employed here to indicate a more general practice of reasoning, employed, for example, by professional historians (see, http://en.wikipedia.org/wiki/Counterfactual_history) and theologians (see, <http://en.wikipedia.org/wiki/Molinism>). For evaluative purposes, an alternative to the counterfactual technique is a “dosage” — “before and after” — technique but adequate “before” and “after” information can be hard to ascertain.

⁹³ See Link and Scott, *Op. Cit.*, 2011 for a discussion of the Counterfactual Evaluation Method (not to be confused with the counterfactual investigative *technique*) and the Spillover Evaluation Method.

and that in the absence of the FPDM the industry would have borne higher costs, and, perhaps, would have expanded less rapidly. In effect, this comparison scenario (“no NIST means no FPDM”) requires the application of the traditional evaluation method. It is hypothesized that there would be no comparable private sector alternative to the FPDM in the absence of NIST’s unique capabilities as “honest broker” and “measurement standards conduit.” The anticipated economic benefits stream — the widening of the gap between buyers’ willingness to pay a higher price and actual market price (what economists refer to as “consumer surplus”); faster growth of FPD applications; the transfer of measurement device designs; and the cost reductions in company operations and the SDO consensus-making process — would not have been generated absent NIST’s involvement.

Three observations justify this comparison scenario. First, the FPDM is an unusually comprehensive measurement standard, so much so that some regard it more as a “guidebook” than a standard. (“It’s not a standard because it doesn’t recommend one thing,” in the words of one industry observer.) It provides the user with choices rather than requiring compliance with “one right way” to measure. The FPDM features its agnosticism on *what* to measure and focuses on *how* to measure:

The standard is a measurement standard, not a compliance standard, nor a prescription for calibration or adjustment. . . . What people do with the results is their own business, but we wanted to be sure it was measured correctly. The goal of a measurement standard is to provide unambiguous methods so that everyone would get the same result on the same display.⁹⁴

This aspect of the FPDM, alone, suggests that reproducing the relationship between the FPDM Workgroup and NIST in another standards organization might not have been at all likely.

Second, many close observers suggest that NIST’s FPDL was the “secret ingredient” in the development of the FPDM; that the standard simply would not have emerged in anything like its current form absent the vision and knowledge of NIST’s staff Workgroup representatives.⁹⁵

Coupled with the unusual scope of the FPDM, it is difficult to imagine that the FPDM Workgroup-FPDL collaboration could have been replicated in an alternative SDO existing at the time.

Perhaps the most important reason for the chosen counterfactual comparison scenario is that it became apparent that positing an alternative SDO and assessing the effectiveness with which it might have achieved tasks actually accomplished under the auspices of

⁹⁴ Flat Panel Display Measurements Standard (FPDM) Version 2.0, Video Electronics Standards Association, Display Metrology Committee, June 1, 2001, p. 3.

⁹⁵ The “acknowledgements” section of the FPDM states, “Most of the credit for creating both versions of the standard should go to . . . Dr. Edward F. Kelley. His experienced insights, originality, and hard work have been an inspiration to us all.” *Ibid.*, p. 4.

VESA would entail an implicit evaluation of VESA relative to an alternate SDO. That evaluation is beyond the scope of this assessment.

4.4 Economic Impact Timeframe (1992-2010)

The significant FPDM timeline events are as follows:

- 1992 — NIST Flat Panel Display Laboratory (FPDL) established.
- 1995 — VESA organizes the FPDM Workgroup at the instigation of Joseph Miseli (Sun Microsystems) and Douglas Baker (Compaq). Dennis Bechis (NIDL) was the first chairman followed soon thereafter by Ed Kelley, of NIST's FPDL, who was also the editor of FPDM 1.0 and 2.0.
- 1998 — FPDM 1.0 released.
- 2001 — FPDM 2.0 released.
- 2007 — VESA's FPRM Workgroup reorganized within the Society for Information Display (SID) as the International Committee for Display Metrology (ICDM) and continues the development of the Display Measurement Standard (DMS), a follow-on to FPDM 2.0 with Ed Kelley as editor.
- 2010 — NIST discontinues Display Metrology project funding.

4.5 Economic Impact Variables⁹⁶

Two kinds of cost-avoidance impact variables were identified:

- Company metrology-related cost avoidance due to the availability of the FPDM (annual hours x fully burdened hourly compensation x years utilized)
- SDO consensus-making cost avoidance due to NIST's participation in the FPDM Workgroup (annual hours x fully burdened hourly compensation x publication acceleration (years) due to NIST participation).

See Appendix C for FPDM Standard Economic Impact Survey instrument.

⁹⁶ As discussed in Section 5.1, the survey data elements ultimately obtained were significantly fewer than originally anticipated. Only the economic impact variables finally estimated are identified here.

5 Survey Findings

5.1 Survey Strategy, Population, and Sample

Two overlapping groups served as the population for the survey and follow-up interviews conducted for this impact assessment:

- Members of the International Committee for Display Metrology — ICDM (a committee under the Society for Information Display — SID), including former members of VESA’s FPDM Workgroup
- Organizations that purchased FPDM 2.0 from VESA.

The survey population was chosen because of their interest and familiarity with the subject matter and their first-hand knowledge of the documentary standard development process. They represent all the value chain tiers of the flat panel display industry including government organizations, certification agencies, universities, measurement standards organizations, FPD integrators, measurement equipment manufacturers, display manufacturers, national measurement laboratories, and related standards groups.^{97,98}

A detailed survey was posted on the ICDM website and members were encouraged to complete the survey on numerous occasions.⁹⁹ Despite continuous encouragement of ICDM committee members, the number of responses remained low. In order to increase the number of respondents, a second survey phase was launched, focused first on other standards organizations with a history of interest in the FPDM, and secondly on purchasers of VESA’s FPDM 2.0. In the second phase of the survey, the survey was dramatically reduced to reflect the questions that respondents appeared most likely to answer.¹⁰⁰ With this significant additional effort a total of sixteen responses were obtained.

⁹⁷ Joseph Miseli, ICDM. Personal communication, September 20, 2010.

⁹⁸ Systematic information on the industry composition of FPDM purchasers was not readily available. It is assumed that the industry composition of the entire survey population (ICDM and FPDM 2.0 purchasers) reflects the industry composition of the ICDM.

⁹⁹ Unfortunately, as a matter of ICDM policy the authors were not granted access to individual ICDM members’ contact information.

¹⁰⁰ The “reduced survey” approach required that several potentially important facets of economic impact be abandoned. These included, in order of priority: willingness to pay benefits (a novel approach to making this estimate was being tested), measurement device design transfer benefits, educational/tutorial workshop benefits, and an assessment of the quality dimension of the FPDM (discussed in section 3.3.3 of this report). At least one significant FPD manufacturer refused to participate because the respondent regarded the framing of some of the survey questions as flawed, arguing, essentially, that the periodization used in the survey instrument (1992-1998 and 1999-2007) was too broad and that this would result in erroneous results. However, using a more precise periodization would have made even greater demands on potential respondents. It is typical for detailed microeconomic impact assessments to face difficult trade-offs between the number of survey respondents, on the one hand, and the depth of information required for insightful details about company operations and resource use on the other hand. Due to perceived risks to proprietary information, organizations are often reticent to share information that is essential for the assessment microeconomic impact. Famously, one of the most important and seminal articles in R&D

5.2 Qualitative Findings

The impact of the FPDM appears far greater than this impact assessment is able to quantify. As suggested in the discussion of the emergence of the FPDM at a key juncture in the “take off” of the PC notebook market (the so-called “killer app”), discussed in section 3.2 above), and the ever-widening and rapidly growing markets for FPD applications, an industry measurement expert describes the sweep of the FPDMs impact, even though he was unable to provide supporting data:

Before [FPDM], display characterization was the wild west of deceptive advertising and claims. ... NIST, realized that the emerging flat panel display technology created new problems for device characterization and performance assessment. ... One goal of [the FPDL] was to establish benchmarks for performance that could be applied uniformly and without bias to characterize these emerging technologies. ... Flat panel display technology over the past 20 years has emerged as the dominant visual interface. Its importance as core enabler of so many products today cannot be underestimated. ... There were many technical and manufacturing hurdles that had to be overcome to enable these devices to match the older technologies of optical projection using film and CRT based television. Not one but several types of flat panel display core technologies emerged. ... Each of these technologies employed unique system architectures for light creation and or spatial and temporal modulation of the video signal. Each due their unique method of creating imagery created unique challenges for performance characterization. ... As these technologies emerged and continue to emerge into the marketplace, new challenges are constantly being created.

While systematic data on this facet of the FPDM’s impact are not available, one test equipment manufacturer with average annual sales of \$700,000 (2005-2010) estimated that, without FPDM, sales would have been much lower, in the range of only \$200,000 - \$500,000 annually.

Intense competition in the FPD industry forces prices below some consumers’ willingness to pay. Economists call this benefit, “consumer surplus.” While survey data was insufficient to systematically estimate what are undoubtedly very large economic benefits, a few survey respondents indicated that FPDM increased consumer surplus (increased willingness to pay above competitive market prices) by an average of 36 percent, 36 cents worth of value for each dollar actually spent by consumers for FPDM-supported products.

evaluation literature, and one published in a leading academic journal, not only used a small sample, but explains as why those doing practical, real-world economic evaluations of investments are often forced to use small samples. See, Edwin Mansfield, et al., “Social and Private Rates of Return from Industrial Innovations,” *The Quarterly Journal of Economics*, Vol. 91, No. 2 (May 1977), pp. 221-240. For the continued relevance of Mansfield’s evaluation work, see Link and Scott, *Op. Cit.*, 2011, pp. 28-29.

A representative of the FPD-optical-measurement-equipment-segment of the industry value chain, and much closer to the direct impacts of the FPDM, observed:

The FPDM has been a very valuable roadmap for our R&D activities over the past 10 years. From inception, the structure, clarity, and pragmatism of the standard has served all of us in the equipment business by defining a set of meaningful measurements (with back-up discussions on methodology and metrology) that could be implemented with practical and robust solutions. ... It's impossible to quantify the savings to our R&D effort, but I can say with confidence the FPDM standard has given us a solid script/roadmap to which we developed test solutions (options). We've promulgated the standard in our sales discussions with panel makers, brand name leaders, ODMs, and component makers. ... The FPDM's value to us equipment makers & solution-providers is immense. However for the broader industry, and for those on either side of a display value-exchange (i.e., up and down the food chain), the FPDM is even more important. It provided the vernacular, language, sound metrology, well thought-out & robust (repeatable and sufficiently accurate) test methods, without endorsement of a particular solution or equipment maker.

Equipment calibration services have also been affected by the FPDM. One representative expressed the importance of the FPDM for sophisticated FPD users and speculates that it also had effects on adjacent markets over and above its direct FPD market impacts:

[The FPD] industry is now ... able to vet their products more uniformly and with greater understanding. Also, U.S. government users of displays have a much better handle on which displays will serve their mission objectives, based on the methods in FPDM. Finally, the medical-imaging community is using FPDM concepts to test displays for acceptability and also to calibrate them. ... As for the impact of FPDM on our market, [our product] hit the market just about the time Version 2.0 of FPDM emerged. I could speculate that the success of [that product line] (and ... of our competitors) is partially the result of calibration-consciousness imparted by the FPDM.

Regarding the FPDM's potential for reducing the cost of the consensus-making process in related SDOs, a medical instruments community representative wrote:

The FPDM has influenced the way we perform measurements in the medical display community. It has directly affected recommendations from professional organizations like the AAPM [American Association of Physicists in Medicine] and was extremely beneficial and a reference for work done by the IEC Standard group on medical image display (TC62BWG36). I expect the new version under final revisions will be even more beneficial, since it is seen as a useful and needed reference.

In addition, two international standards committees used text from the FPDM with formal permission from VESA:

- ISO 9241-302:2008 Ergonomics of human-system interaction -- Part 302: Terminology for electronic visual displays
- ISO 9241-305:2008 Ergonomics of human-system interaction -- Part 305: Optical laboratory test methods for electronic visual displays.¹⁰¹

No estimate of the time saved by the ISO technical committees is available but, based on the experience of the FPDM Workgroup discussed below, it is prudent to suggest that the availability of the FPDM's language saved the relevant ISO technical committees many hours of consensus-making time worth thousands or hundreds of thousands of dollars.

Referring to the forthcoming ICDM/SID revision of the FPDM (the DMS), another data-poor respondent, representing a large FPD manufacturer, articulates a perspective that reflects the importance of the flat panel display measurement to the long-growing applications market:

Dollarizing the value of DMS and its successive revisions may be impossible, but we know it will be very important.... Displays are becoming pervasive throughout today's information society, and having a uniform and consistent means of measuring and evaluating them is essential.

Finally, a defense-related OEM representative also believes strongly in the cost-effectiveness of the original FPDM and its successors:

The lack of uniform standards for display measurement [would be] is a real handicap, especially for defense and military programs, where we rely on the data to assess the ergonomics, human factors, and hence mission readiness of display systems. Using a well-defined measurement process as well as the well-understood specifications is the key to getting those deployments right the first time.

As these qualitative observations indicate, industry representatives believe that the economic impact of the FPDM was, and will continue to be, broad and deep. Despite an attempt to measure many facets of the FPDM's economic impact alluded to above, only a thin sliver of these benefits proved possible to estimate quantitatively resulting in a very conservative quantitative estimate of the true economic impact of the FPDM.

5.3 Quantitative Findings

Survey respondents were requested to provide information identifying the markets within which they operate, data concerning their market share, the company resources devoted to FPDM-related measurements before and after FPDM 1.0 and 2.0. Survey respondents also provided estimated savings in labor time devoted to the SDO consensus-making process due to the presence of NIST staff in the FPDM Workgroup activities, the

¹⁰¹ Paul Boynton, personal communication, August 8, 2011.

acceleration of the consensus-making process due to NIST's role, and the extent to which the technical substance of the FPDM carries over to the forthcoming FPDM revision — the ICDM's DMS.

The estimates of the annual FPDM-labor time saved by a company due to the availability of the FPDM (referred to in the language of the survey as “do-it-yourself metrology labor avoidance”) ranged from fifty (50) hours for small companies to fourteen thousand (14,000) hours for large aerospace firms. Double-checking the latter number, the respondent confirmed, “the FPDM is very valuable to [our company]. We get a lot out of it. We invested a lot of time and effort helping to develop it.” For the period 1998-2010, net benefits from this source alone are estimated at approximately \$2.4 million annually.

The estimates of annual SDO consensus-making process time avoided by companies due to the active involvement of NIST staff in FPDM Workgroup activities ranged from twenty (20) hours for companies only peripherally involved in the core activities of the Workgroup, to one thousand (1000) hours for companies who took the deliberations of the Workgroup most seriously. It was estimated by a knowledgeable independent observer of the FPDM Workgroup's activities, that ten companies participated in Workgroup activities regularly and the majority dedicated fewer than one hundred (100) hours to the process annually. He confirmed that a few companies dedicate three hundred to one thousand (300-1000) hours annually, an estimate that squares with the information provided by survey respondents. For the period 1995-2001, net benefits from this source are estimated at approximately \$640,000 annually. In addition, several survey respondents estimate that the FPDM was published relatively fast due to NIST's participation, an average of 4.5 years faster in the case of FPDM 1.0 (1998) and an estimated 7 years faster for FPDM 2.0 (2001).

Fortunately most of the respondents who provided full survey responses, including market share estimates, represented different horizontal segments of the FPD value chain so that extrapolating their labor savings to their respective value chain segment is straightforward.¹⁰²

Finally, it is anticipated that the benefits associated with the FPDM will continue to yield benefits to industry beyond the study period. Survey respondents estimate that sixty-five percent of the measurement cost-avoidance attributed to the content of the FPDM will carry over to the revised DMS standard expected to be released in 2011. That standard will address a wide array of additional measurement challenges resulting from the continuing expansion of FPD applications. None of those carry-over reductions in cost are measured as a part of the time series of FPDM benefits used for the evaluation metrics estimated here, thus providing another significant source of the conservative, lower-bound nature of evaluation metrics presented in this study.

¹⁰² Where market share estimates were not provided, or were ambiguous, on-line sources were consulted to estimate a scaling factor based on published market share estimates.

6 Quantitative Analysis

6.1 Benefits

Broadly speaking, only two types of benefits were estimated for FPDM users and FPDM Workgroup participants:

- “Do-it-yourself” metrology labor avoidance
- SDO consensus-making labor time avoidance.

Estimates of “do-it-yourself metrology labor cost avoidance” benefits reflect the respondents’ observations that prior to the promulgation of the FPDM, weeks and weeks of discussion and discovery could be dedicated to developing approaches to making measurements, especially for ‘contentious parameters’ such as ‘set up conditions’ (a focus of the FPDM). The development of the approach included ongoing discussions with customers — for whom the displays were being made — or with display manufacturers. The metrology cost avoidance estimates reflect the extent to which the FPDM changed that.

Similarly, estimates of SDO consensus-making cost avoidance benefits reflect the respondents’ counterfactual estimates of the additional time they would have to have invested in the absence of support from NIST’s FPDL staff, to produce a measurement standard of similar quality. It provides a unified “buffet” of measurements and set up conditions that anyone can use and combine in any way they need but with the underlying metrology clearly established.

A time series of these benefits estimates for the period 1992-2010 is provided in Table 6-1. Benefit estimates for the 1992-1997 period include only the SDO process cost avoidance attributable to NIST’s staff contributions to the FPDM Workgroup established in 1995. Thereafter, the benefits ramp up by the amount of added benefits that accrue to industry in terms of do-it-yourself metrology cost avoidance. The metrology-cost avoidance benefits cover the period from the publication of FPDM 1.0, in 1998, to 2010 because the future revision of the VESA FPDM 2.0 (ICDM’s DMS) has not yet been released so those annual benefit estimates attributable to FPDM 2.0 continue to accrue to industry. The SDO consensus process benefits begin in 1995 and continue to 2001. Thereafter, the consensus process cost avoidance benefits accrue to the future DMS, the revision of FPDM 2.0.

Table 6-1. FPDM-Related Benefits (Nominal \$)

Year	Metrology Labor Avoidance (Nominal \$)	Consensus Labor Avoidance (Nominal \$)
1992	0	0
1993	0	0
1994	0	0
1995	0	1,128,483
1996	0	1,149,936
1997	0	1,170,296
1998	2,427,106	1,183,487
1999	2,462,842	573,265
2000	2,516,263	585,700
2001	1,964,988	598,953
2002	1,996,612	0
2003	2,039,660	0
2004	2,097,534	0
2005	2,167,568	0
2006	2,238,296	0
2007	2,304,147	0
2008	2,353,936	0
2009	2,376,045	0
2010	2,398,718	0

6.2 SDO Costs and NIST Expenditures

Two categories of costs are estimated for this assessment:

- SDO costs of two kinds (VESA administrative costs and the labor time donated to the FPDM Workgroup by member companies)
- NIST expenditures in support of the FPDL and the FPDM Workgroup.

VESA’s FPDM Workgroup administrative costs of ~\$9,000 (2010 dollars) annually were estimated by a senior VESA administrator familiar with the activities of the Workgroup. Private sector costs of participating in the Workgroup were estimated from survey responses scaled to reflect the estimated number of companies that regularly participated in Workgroup activities, estimated by active members.

NIST expenditures are estimated from historical NIST budget data projected back to the relevant years, 1992-2001. Due to NIST budgeting practices in the early period of the assessment timeframe (1992-2000) project budgets were “pieced together” from a wide array of sources making it difficult to clearly identify the composition of the FPDL

budget. In 2001, the budgeting system underwent a significant change, and then in 2004 there was another significant administrative change. For the period 2004 -2009 the FPDL budget is consolidated and easily tracked, even though these NIST costs are not pertinent to the evaluation of the FPDM since it was released in 2001. Consultation with former NIST project staff confirmed that the actual level of funding for the FPDL was more or less stable over the entire study timeframe; that the historical budget practices make it difficult to capture that stable level without a considerable expenditure of staff time; and, therefore, that back-casting the 2004-2009 average budget would reasonably reflect the actual historical pattern of NIST expenditure. That is the procedure that was followed for constructing the NIST expenditure time series in Table 6-2.

Table 6-2. FPDM Workgroup Costs and NIST Expenditures (Nominal \$)

Year	NIST Expenditures (Nominal \$)	FPDM Workgroup Labor (Nominal \$)	Workgroup Administrative (Nominal \$)
1992	434,663	0	0
1993	444,232	0	0
1994	453,574	0	0
1995	463,036	183,925	6,631
1996	471,838	187,422	6,757
1997	480,192	190,740	6,877
1998	485,605	192,890	6,954
1999	492,755	186,078	7,056
2000	503,443	190,114	7,209
2001	514,835	194,417	7,373
2002	0	0	0
2003	0	0	0
2004	0	0	0
2005	0	0	0
2006	0	0	0
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0

6.3 Measures of Economic Impact

Table 6-3 transforms the nominal costs and benefits reported in Tables 6-1 and 6-2, above, into a series of constant 2010 dollars and provides the basis for the summary economic impact estimates reported below: social rate of return (SRR), net present value (NPV), and benefit-to-cost ratio (B/C). (For a explanation and discussion of these metrics, see Appendix D.)

Table 6-3. Constant 2010 Dollar Benefits and Costs (1992 - 2010)

Year	Constant Dollar Benefits (\$2010)	Constant Dollar Costs (\$2010)	Constant Dollar Net Benefits (\$2010)
1992	0	628,474	-628,474
1993	0	628,474	-628,474
1994	0	628,474	-628,474
1995	1531680	887,114	644,566
1996	1531680	887,114	644,566
1997	1531680	887,114	644,566
1998 FPDM 1.0	4672864	887,114	3,785,750
1999	3872344	874,804	2,997,540
2000	3872344	874,804	2,997,540
2001 FPDM 2.0	3129878	874,804	2,255,074
2002	2398718	0	2,398,718
2003	2398718	0	2,398,718
2004	2398718	0	2,398,718
2005	2398718	0	2,398,718
2006	2398718	0	2,398,718
2007	2398718	0	2,398,718
2008	2398718	0	2,398,718
2009	2398718	0	2,398,718
2010	2398718	0	2,398,718

As discussed in section 5.1 of this report, the economic impact assessment estimates selected areas of the FPDM’s economic impact: industry metrology labor savings that resulted from the adoption of FPDM and consensus-making efficiencies due to NIST’s participation in VESA’s FPDM Workgroup. Only these impacts are captured in the conservative estimates of economic impact shown in Table 6-4.

Table 6-4. Estimate of Economic Impact

Performance Metric	Value
Net Present Value in 1992	\$15,573,930
Net Present Value in 2010	\$56,323,545
Real Social Rate of Return	48%
Benefit-to-Cost Ratio	4

With better data the full impact of the FPDM would be considerably higher and would capture:

- FPDMs impact on the quality of products that use FPDs
- The value to industry of measurement device designs that were a product of NIST's role in the FPDM Workgroup
- Extra benefits to industry of releasing the FPDM sooner than it would have been released, due to NIST's participation
- The codified know-how carried forward into the International Committee on Display Measurement's (ICDM's) forthcoming Display Measurement Standard (DMS).

The first impact metric shown in Table 6-4 (net present value in 1992 — NPV 1992) uses the year NIST's FPDL was founded as the base year and calculates the net present value of the project from the perspective of 1992. The NPV is the inflation-adjusted (real) value of the net benefits (benefits – cost) generated by the project over the course of the study period (1992-2010). If, in 1992, NIST project managers were trying to judge which of two or more projects would yield the highest economic return this is the calculation they would have made. From an economic perspective, if only one of the projects could have been chosen, the chosen project would have been the one with the highest NPV.

The second impact metric (net present value in 2010) is intended to interpret the NPV of the net benefits that actually occurred as a result of the FPDM effort from a somewhat different perspective. If the net benefits that actually accrued to the effort (NPV 1992, ~\$15.6 million) were invested in 1992 and annually earned the cost of capital to the U.S. government (seven percent), the value of those benefits today would be ~\$56 million.¹⁰³

The third impact metric (real social rate of return — SRR) is similar to an internal rate of return calculation, another corporate finance technique used to judge the worthiness of an investment project. The modifier "social" indicates that the value of this performance metric accounts for the benefits and costs that accrue to all beneficiaries, not just the project investors. The SRR is the interest rate (also called the "discount rate") that would reduce the NPV 1992 of the project to zero and reduce the benefit-cost ratio to one —

¹⁰³ The government cost of capital is stipulated as seven percent in Office of Management and Budget (OMB) *Circular no. A-94: Guidelines and Discount Rates for Cost-Benefits Analyses of Federal Programs*, 1992. For a discussion of the rationale of the seven percent discount rate, see, Link and Scott, *Op. Cit.*, 2011 and (OMB) *Circular no. A-4: Regulatory Analysis*, 2003.

hence, the project would breakeven. As a guide to making a decision on an investment project (private or public), if the SRR is higher than the discount rate, the project is acceptable.

Finally, the benefit-to-cost ratio (BCR) is simply the ratio of the NPV of benefits to the NPV of costs. This value indicates that the real value of the benefits of the FPDM effort to all beneficiaries exceeded the costs by a ratio of 4:1.¹⁰⁴

¹⁰⁴ For a comparison of the economic impact of the FPDM effort to other efforts assessed by NIST, see <http://www.nist.gov/director/planning/studies.cfm>. Note that the nature of the FPDM project impacts is somewhat different than those listed on the NIST website because the source of a portion of the FPDM impact benefits derives from SDO operational efficiencies associated with the NIST-VESA's FPDM Workgroup collaboration. Whether the scale of these operational efficiencies is relatively large or small is unknown.

7 Conclusion

NIST devotes considerable resources to the support of industry standards. One of its missions is to assist industry with the standards-related tools and information to compete more effectively in the global marketplace.

In 2010, approximately 350 NIST experts were involved in more than 1300 documentary standards committees. Optimally, these expert resources should go where they are most capable of achieving NIST's goals and objectives. By examining the role of NIST's measurement expertise in a specific case, this economic impact assessment contributes to understanding how the allocation of those expert resources might be optimized.

The selection of the Video Electronics Standards Association's (VESA's) Flat Panel Display Measurement (FPDM) standard from among a short list of potential projects was based on pragmatic considerations. As it turned out, the history of the FPDM project, and the investigation of the way in which NIST's know-how is developed and enters the stream of industry value creation, is a treasure trove of lessons learned. For example:

- *Documentary* standards have significant economic impacts, similar to the economic impact of other types of standards based on various categories of “infratechnologies”
- NIST collaboration with SDOs is a significant technology transfer platform
- NIST involvement in SDOs improves the efficiency of the SDOs operations by mitigating “specsmanship” (reducing consensus-making time) and speeding standard release date
- NIST's measurement know-how played a critical role in the dynamics of this global, knowledge-driven industry, enabling the “structured dialog” that lead to the proliferation of FPD applications.

Reflecting on the history of the FPDM standard may also hold some clues about attributes of the standard development process that indicate if and how NIST should participate in specific SDO projects. The history of NIST's engagement with VESA's FPDM Workgroup suggests that the following organizational attributes are worthy of management consideration when choosing to engage with an SDO:

- Does NIST take a technical leadership role at Workgroup level? (+),
- Is industry participation wide and substantial at the Workgroup level? (+)
- Is NIST's leadership at the Workgroup level anticipatory of industry trends and well supported financially (indicating a NIST strategic priority)? (+)
- Are other SDOs proposing similar or competing standards? (-)

Even though data limitations prevented the estimation of the FPDM's full economic impact, it is clear that the benefits are substantially higher than those measured. While this study's impact metrics account for the full costs of the FPDM's development, only two benefit streams — metrology labor savings and SDO consensus-making efficiencies — are estimated. Other, significantly large benefits streams associated with FPDM Workgroup outputs include:

- FPDs impact on the quality of products that use FPDs and the consumer benefits that accrue from such quality improvements
- The value to industry of measurement device designs that were a product of NIST's role in the FPDM Workgroup
- Extra benefits to industry of releasing the FPDM sooner than it would have been released, due to NIST's participation
- The codified know-how carried forward into the International Committee on Display Measurement's (ICDM's) forthcoming Display Measurement Standard (DMS).

The impact of the FPDM on the quality of products that use FPDs, alone, is no doubt very considerable. FPD applications in the markets for portable computers, desktop monitors, televisions, handheld computers, camcorders, digital still camera, GPS devices, and financial terminals have grown while fierce global competition has driven prices lower and lower. It is likely that professional and general consumers' "willingness to pay" higher prices than prevail in the market would be considerable. These "consumer surplus" benefits probably dwarf the cost savings captured in the economic impact measures presented in this report.

On the account presented here, the scope of those applications was enabled by a fundamental transformation of the quality of the measurement know-how available to sellers and buyers of FPD. That transformation was brought about by the collaboration of NIST's FPDL and VESA's FPDM Workgroup.

Quantitative economic impact metrics, while important, are only one feature of the important insights that come from close, detailed examination of cases like this one.

This case study highlights a facet of the dynamics of global competition that is vitally important to the innovation that drives U.S. prosperity. NIST emphasizes the importance of "infratechnology" to the growth and development of industries and, going forward, to an economic policy that strives to foster U.S. economic growth in a globally competitive world.¹⁰⁵ The collaboration between NIST and VESA may be exemplary from this perspective.

In one of its most concrete forms, "infratechnology" is measurement know-how. As discussed throughout this report, from an economic perspective documentary standards can be vehicle for such know-how and NIST's "honest broker" role can play a significant role in diffusing this measurement know-how. Moreover, this case highlights how the traditional distinctions between product and process technology alone could not account for important developments in the industry. The role of measurement know-how — infratechnology, a NIST core competency — played a central role, embodied in the FPDM.

¹⁰⁵ Gregory Tassej, *The Technology Imperative*, Edward Elgar, 2007.

FPDM Workgroup produced a measurement standard unlike any other by most accounts. NIST's technical staff made a great deal of difference to the outcome, but not all the difference. In addition to technical virtuosity of the FPDL's staff, probably largely because of it, NIST forged a close and effective relationship with its industry counterparts that resulted in expanding markets, increased product quality for a rapidly expanding array of products, and lowered costs of production. In the words of a prominent industry spokesman, "displays are becoming pervasive throughout today's information society, and having a uniform and consistent means of measuring and evaluating them is essential."

The impact assessment demonstrates that *documentary* standards have had significant economic impact. Even as a very conservative measure of economic impact, the performance metric values estimated for the FPDM are similar to the economic impact of other "infratechnologies."¹⁰⁶

Moreover, it appears that NIST's collaboration with SDOs has significant potential for supporting the innovation process that fuels global competition. In the case of the global FPD industry that support took the form of facilitating the application of technologies initially developed in the U.S. but manufactured elsewhere. Still, the value to FPD supplier industries and to consumers of devices and services that incorporate FPD technology is significant.

In addition to benefiting industry operations directly by reducing considerable metrology costs, NIST involvement in VESA improved the efficiency of that organization by reducing a considerable barriers to consensus making — the mitigation of "specsmanship." NIST's close collaboration with VESA and other related SDOs also appears to have served as a platform for the transfer and diffusion of measurement device designs to industry as well.

The Standard Coordinating Office (SCO) aims to support the development of qualitative and quantitative impact assessments of documentary standards and, in time, begin to accumulate and translate "lessons learned" into a strategic management advice about the likely economic impact of NIST staff's SDO collaborations.

¹⁰⁶ See, <http://www.nist.gov/director/planning/studies.cfm>

Appendix A: Types of Documentary Standards ISO/IEC Guide 2: 2004

A *basic standard* has a wide-ranging coverage or contains general provisions for one particular field, such as a standard for metal that can affect a wide range of products from cars to fasteners.

Terminology standards are concerned with terms, usually accompanied by their definitions. The standards define words that permit industries or parties entering into a transaction to use a common, clearly understood language.

Testing standards are concerned with test methods, sometimes supplemented with other provisions related to testing, such as sampling, use of statistical methods, or the sequence of tests. They are generally used to assess the performance or other characteristics of a product.

Product standards specify requirements to be fulfilled by a product (or a group of products) to establish its fitness for purpose. Such standards can also address other issues, including packaging and labeling or processing requirements.

Process standards specify requirements to be fulfilled by a process to establish its fitness for purpose. For example, a process standard could cover requirements for the effective functioning of an assembly line operation.

Service standards, such as for servicing or repairing a car, establish requirements to be fulfilled by a service to establish its fitness for purpose.

Interface standards, such as requirements for the point of connection between a telephone and a computer terminal, specify requirements concerned with the compatibility of products or systems at their points of interconnection.

Standards on data to be provided contain a list of characteristics for which values or other data are to be stated for specifying the product, process or service. This type of standard generally provides a list of data requirements for a product or service for which values need to be obtained.

Appendix B. Flat Panel Display Laboratory Publications and Presentations

STANDARDS

E. F. Kelley, "Understanding SpecsmanSHIP," 2007 Display Applications Conference, Society for Information Display, Invited Paper 7.1, San Francisco, CA, October 23-25, 2007.

P. Boynton, "Display Metrology Concerns in International Standards," Proceedings of the Third Americas Display Engineering and Applications Conference (ADEAC '06), October 2006 (2006)

P. Boynton, "The Challenge to Display Metrology and Standards: Whom Do You Trust?" Digest of the IEEE Broadcast Technology Society/IBC2006, Amsterdam, September 7, 2006 (2006) (invited paper and talk)

P.A. Boynton, "Display Metrology Concerns in International Standards," Council for Optical Radiation Measurements annual conference, Boulder, Colorado, May 11, 12, 2005

E. F. Kelley and S. Pala, "Challenges in Automotive Display Standards," Council for Optical Radiation Measurements annual conference, Boulder, Colorado, May 11, 12, 2005.

P. A. Boynton, "The goals of good display metrology," The Display Standard, May 2005

E. F. Kelley, "Plotting the Course of the Next VESA Flat Panel Display Measurements Standard," J. Society for Information Display, Vol. 13, No. 1, pp. 67-79, January 2005.

E. F. Kelley, "What Do the Specifications Mean?" Proceedings of the First Americas Display Engineering and Applications Conference (ADEAC 2004), Society for Information Display, Ft. Worth, TX, USA, pp. 15-18, October 26, 2004.

P. Boynton, "Display Metrology Concerns in International Standards," Presentation Materials of Special Sessions of the IMID 2nd Flat Panel Display Standardization Session, Daegu, Korea, August 2004

P. Boynton, "The Challenge to Display Metrology and Standards: Whom Do You Trust?" Workshop and Special Evening Session of the SID 24th International Display Research Conference, pp. 46-57, August 2004.

E. F. Kelley, "Plotting the Course of the Next VESA Flat Panel Display Measurements Standard," 2004-SID International Symposium Digest of Technical Papers, Society for Information Display, Invited Paper 7.1, Vol. 35, Book 1, pp. 78-81, Seattle, WA, May 25, 2004.

P. A. Boynton, and E. F. Kelley, "ISO and VESA Standardization for FPDs", Proceedings of the Special Session on Standardization of Flat Panel Displays, The 3rd International Meeting on Information Display, Daegu, Korea, July 2003

E. F. Kelley, "Vehicular Display Metrology Seminar," Society for Information Display Metropolitan Detroit Chapter, 8th Annual SID Symposium on Vehicle Displays, Detroit, MI, October 16-18, 2001.

E. F. Kelley, "SAE J1757 Committee Report on Proposed Reflection Measurements," 8th Annual SID Symposium on Vehicle Displays, October 16-18, 2001.

P. Boynton and C. Fenimore, "Characterization of Projection Systems for the MPEG-4 Digital Cinema Compression Scheme Evaluation," NIST IR 6792, 2001.

E. F. Kelley, "Flat Panel Display Measurements and Standards," Applications Seminar A-4, 2000-SID International Symposium, Society for Information Display, Long Beach, California, May 17, 2000.

Edward F. Kelley, George R. Jones, Paul A. Boynton, Michael D. Grote, and Dennis J. Bechis. "A Survey of the Components of Display Measurement Standards." *Journal of the Society for Information Display*, Vol. 3, No. 4, pp. 219-222, December 1995.

Edward F. Kelley, George R. Jones, Paul A. Boynton, Michael D. Grote, and Dennis J. Bechis. "A Survey of the Components of Display Measurement Standards." *Society for Information Display International Symposium Digest of Technical Papers*, Vol. 26, Orlando, FL, pp. 637-640, May 23-25, 1995.

Dennis J. Bechis, Michael D. Grote, David P. Bortfeld, Lawrence H. Hammer, Michael J. Polak, Edward F. Kelley, George R. Jones, and Paul A. Boynton. "Display Measurement Round Robin," *Society for Information Display International Symposium Digest of Technical Papers*, Vol. 26, pp. 641-644, Orlando, FL, May 23-25, 1995.

STRAY LIGHT MANAGEMENT

E. F. Kelley, J. Penczek, and P. A. Boynton, "Character Contrast under Uniform Ambient Conditions," 2009-SID International Symposium Digest of Technical Papers, Society for Information Display, San Antonio, Texas, USA, paper 24.1, pp. 321-324, May 31 - June 5, 2009.

E. F. Kelley, "Character Contrast," *Information Display Magazine*, January 2009.

P.A. Boynton and E.F. Kelley, "Comparing Methodologies for Determining Resolution from Contrast in Projection Display Systems," *Projection Displays XI*, Proceedings of the SPIE, Vol 5740, January 2005.

P. Boynton, "Tools and Diagnostics to Assess and Improve Projection Display Metrology Capabilities," Proceedings of the First Americas Display Engineering and Applications Conference (ADEAC 2004), Society for Information Display, Ft. Worth, TX, USA, pp. 15-18, October 26, 2004

P. Boynton, "Methods to Eliminate Stray Light for Display Characterization," Proceedings of the USDC High Information Content Display Systems Conference, Arlington, VA, September 2004 (2004)

P. A. Boynton, E. F. Kelley, and J. M. Libert "Projection Display Metrology at NIST: Measurements and Diagnostics," Liquid Crystal Materials, Devices, and Applications X and Projection Displays X, Proceedings of the SPIE, Vol. 5289, pp. 302-313, January 2004 (2004)

E. Kelley and P. Boynton, "Seamless Frusta Creation for Stray-Light Management in Optical Devices," NIST IR 6637. December 1, 2003. (2003)

Edward F. Kelley, Paul A. Boynton, and John M. Libert, "Evaluation of Luminance Probes Used for Accurate Contrast Measurements in Medical Displays," Council for Optical Radiation Measurements Conference, Stanford University, Menlo Park, California, June 19-20, 2003.

A. Badano, S. Pappada, E. F. Kelley, M. J. Flynn, S. Martin, and J. Kanicki, "Luminance probes for contrast measurements in medical displays," 2003-SID International Symposium Digest of Technical Papers, pp. 928-931, Society for Information Display, Baltimore, MD, May 18-23, 2003.

P. Boynton and E. Kelley, "A Liquid-Filled Camera for the Measurement of High-Contrast Images," Cockpit Displays X, Proceedings of the SPIE, Vol. 5080, (April 2003).

P. A. Boynton, "Evaluation of a Liquid-Filled Camera for Measurement of Shadow Detail. Part I: Sensor Evaluation," NIST IR 6900, August 2002.

P. Boynton and E. Kelley, "Stray Light Elimination Tube Prototype," NIST IR 6861, March 2002

P. A. Boynton and E. F. Kelley, "Stray Light Compensation in Small Area Contrast Measurements of Projection Displays," Projection Displays VIII, Proceedings of the SPIE, Vol. 4657, pp. 122-130 (January 2002).

P. Boynton and C. Fenimore, "Characterization of Projection Systems for the MPEG-4 Digital Cinema Compression Scheme Evaluation," NIST IR 6792, 2001.

P. A. Boynton and E. F. Kelley, "Compensation for Stray Light in Projection-Display Metrology," 2001-SID International Symposium Digest of Technical Papers, Society for Information Display, Vol. 32, pp. 334-337, San Jose, CA, June 4-8, 2001.

J. W. Roberts and E. F. Kelley, "Measurements of Static Noise in Display Images," Proceedings of the SPIE V4295B-27, Electronic Imaging Symposium, San Jose, CA, pp. 211-218, January 23, 2001.

P. A. Boynton, "Tools and Diagnostics for Projection Display Metrology," NISTIR 6591: Digital Cinema 2001 Conference Proceedings, Gaithersburg, MD, January 11-12, 2001

P. A. Boynton and E. F. Kelley, "Stray Light Elimination in Making Projection Display Measurements," Flat Panel Display Technology and Display Metrology, Proceedings of the SPIE Vol. 3636, pp. 232-239 (1999).

E. F. Kelley, "Simulated-Eye-Design Camera for High-Contrast Measurements," International Society for Optical Engineering (SPIE) Electronic Imaging Conference, San Jose, CA, January 29, 1999, Proceedings of SPIE, Flat Panel Display Technology and Display Metrology, Vol. 3636, pp. 184-190.

P. A. Boynton and E. F. Kelley, "Is the Measurement of Front-Projector Characteristics an Impossible Task?", Information Display, Vol. 14, No. 10, pp. 34-37, December 1998.

P. A. Boynton and E. F. Kelley, "Small-Area Black Luminance Measurements on a White Screen Using Replica Masks," 1998-SID International Symposium Digest of Technical Papers, Society for Information Display, Vol. 29, pp. 941-944, Anaheim, CA, May 17-22, 1998.

P. A. Boynton and E. F. Kelley, "Accurate Contrast-Ratio Measurements Using a Cone Mask," 1997 Society for Information Display (SID) Symposium, Digest of Technical Papers, May 11-16, 1997, Boston, MA, Sec 32.1, pp. 823-826 (May 1997).

P. A. Boynton and E. F. Kelley, "Measuring the Contrast Ratio of Displays: It's Not Trivial." Information Display, Vol. 12, No. 11, pp. 24-27, November 1996.

DIAGNOSTICS

P. A. Boynton, J. M. Libert, E. F. Kelley, C. Wall, C. Campbell, R. Baribeau, "A Color Gamut Assessment Standard: An Inter-Laboratory Measurement Comparison," Council for Optical Radiation Measurements annual conference, Boulder, Colorado, May 11, 12, 2005

P. Boynton, "Methods for Assessing Display Measurement Capabilities," Cockpit Displays XI, Proceedings of the SPIE, Vol. 5543, September 2004 (2004)

J. Libert, E. Kelley, P. Boynton, S. Brown, C. Wall, and C. Campbell, "A Color Gamut Assessment Standard: Construction, Characterization, and Inter-Laboratory Measurement Comparison," Fourth Oxford Conference on Spectrometry, SPIE vol. 4826 (August 2003).

P. A. Boynton and E. F. Kelley, "Display Metrology and ISO and VESA Standardization for FPDs", Display Asia, September 2003.

J. M. Libert, E. F. Kelley, P. A. Boynton, S. W. Brown, C. Wall, and C. Campbell, "A Color Gamut Assessment Standard: Construction, Characterization and Inter-Laboratory Measurement Comparison," Fourth CORM Oxford Conference on Spectrometry," Davidson, NC, June 9 - 13, 2002.

E. F. Kelley, "Electronic Display Metrology--Not a Simple Matter," Proc. of SPIE, Vol. 4450, pp. 44-53, NIST/SPIE Centennial Symposium/Celebration, San Diego, CA, August 1, 2001.

E. F. Kelley and J. V. Miseli, "Setup Patterns for Display Measurements - Version 1.0," NISTIR 6758, 14 pp., June 2001.

J. M. Libert, P. A. Boynton, E. F. Kelley, S. Brown, Y. Ohno, and F. Manoocheri, "Display Measurement Assessment Standard: Program Update and Preliminary Colorimetric Measurement Inter-comparison," Council for Optical Radiometric Measurement (CORM) Annual Conference Presentation Materials, Session III: Inter-Comparisons, Gaithersburg, MD, May 14-16, 2001 (May 2001).

P. A. Boynton and E. F. Kelley, "Light Measuring Device Diagnostics for the Photometric and Colorimetric Measurement of Flying-Spot Displays," Proceedings of the SPIE V4295, Electronic Imaging Symposium, San Jose, CA, January 23, 2001.

J. M. Libert, Paul A. Boynton, Edward F. Kelley, Steven W. Brown, Yoshihiro Ohno, and Farshid Manoocheri, "A Standard Illumination Source for the Evaluation of Display Measurement Methods and Instruments," Proceedings of the SPIE V4295, SPIE Electronic Imaging Symposium, San Jose, CA, January 23, 2001.

J. M. Libert, P. A. Boynton, E. F. Kelley, S. Brown and Y. Ohno, "An Assessment Standard for the Evaluation of Display Measurement Capabilities," Proceedings of the Society for Imaging Science & Technology (IS&T) / Society for Information Display (SID) Eighth Color Imaging Conference: Color Science and Engineering, Scottsdale, AZ, November 7-10, 2000.

P. A. Boynton, E. F. Kelley, S. Highnote, R. Hurtado, "Diagnostics for light measuring devices in flying-spot display measurements," Projection Displays 2000: Sixth in a Series, Proceedings of the SPIE Vol. 3954, pp. 42-51 (2000)

E. F. Kelley, "Polystyrene Box Uniform Light Sources," Council for Optical Radiation Measurements, May 4-6, 1999.

P. A. Boynton, "Evaluation of Light Measuring Devices for Flying-Spot Display Measurements," Council for Optical Radiometric Measurement (CORM) Annual

Conference Presentation Materials, Session IV: Optical Metrology of Displays, Gaithersburg, MD, May 3-6, 1999 (May 1999).

P. A. Boynton and E. F. Kelley, "Assessment of Colour Measurement Systems Using Interference Filters," Proc. CIE Expert Symposium '97 on Colour Standards for Imaging Technology, Nov 21-22, 1997, Scottsdale, AZ, publ. Commission Internationale de L'Eclairage (CIE), Vienna, Austria, pp. 22-27 (1998).

P. Boynton, Y. Ohno, and E. Kelley, "Interference Filter Characterization of Spectroradiometers and Colorimeters," Society for Information Display International Symposium Digest of Technical Papers, Vol. 27, San Diego, CA, pp. 207-210, May 12-17, 1996.

REFLECTION METROLOGY

E. F. Kelley, J. Penczek, and P. A. Boynton, "Character Contrast under Uniform Ambient Conditions," 2009-SID International Symposium Digest of Technical Papers, Society for Information Display, San Antonio, Texas, USA, paper 24.1, pp. 321-324, May 31 - June 5, 2009.

S. Kim, E. F. Kelley, and J. Penczek, "Robustness of Display Reflectance Measurements: Comparison between BRDF and Hemispherical Diffuse Reflectance," 2009-SID International Symposium Digest of Technical Papers, Society for Information Display, San Antonio, Texas, USA, paper 24.2, pp. 325-327, May 31 - June 5, 2009.

E. F. Kelley, "Character Contrast," Information Display Magazine, January 2009.

J. Penczek, E. F. Kelley, and S. Kim, "Robustness of Display Hemispherical Reflectance measurement Apparatus," Invited Paper 41-1, IMID/IDMC/Asia Display 2008 Digest, pp. 1355-1357, Ilsan, Korea, October 13-17, 2008.

E. F. Kelley, "Diffuse Clarification," Information Display Magazine, Vo. 24, No. 2, p. 8 ff., February 2008.

E. F. Kelley, "Metrology and Robustness of Bright-Room Contrast Measurement," 2007-SID International Symposium Digest of Technical Papers, Society for Information Display, Invited Paper 20.1, pp. 1034-1037, Long Beach, CA, May 21-25, 2007.

Edward F. Kelley, Max Lindfors, and John Penczek, "Display Daylight Ambient Contrast Measurement Methods and Daylight Readability," J. Society of Information Display, Vol. 14, No. 11, pp. 1019-1030, November 2006.

E. F. Kelley, "Diffuse Reflectance and Ambient Contrast Measurements Using a Sampling Sphere," Proceedings of the Third Americas Display Engineering and Applications Conference (ADEAC 2006), Society for Information Display, Atlanta, GA, USA, pp. 1-5, October 24,26, 2006.

E. F. Kelley, "Daylight and Sunlight Display Readability Measurement Methods," Proceedings of the Second Americas Display Engineering and Applications Conference (ADEAC 2005), Society for Information Display, Portland, Oregon, USA, pp. 1-4, October 25-27, 2005.

E. F. Kelley, "Variable-Radius Source Method to Separate Specular Component from Haze Peak," Council for Optical Radiation Measurements annual conference, Boulder, Colorado, May 11, 12, 2005

E. F. Kelley and J. Penczek, "Scalability of OLED Fluorescence in Consideration of Sunlight-Readability Reflection Measurements," 2004-SID International Symposium Digest of Technical Papers, Society for Information Display, Paper P.54, Vol. 35, Book 1, pp. 450-453, Seattle, WA, May 25, 2004.

E. F. Kelley, "Sensitivity of Display Reflection Measurements to Apparatus Geometry," 2002-SID International Symposium Digest of Technical Papers, Society for Information Display, Boston, MA, pp. 140-143, May 19-24, 2002.

E. F. Kelley, "SAE J1757 Committee Report on Proposed Reflection Measurements," 8th Annual SID Symposium on Vehicle Displays, October 16-18, 2001.

E. F. Kelley, "Impediments to Reproducibility in Display Metrology," Digital Cinema 2001 Conference, NIST, pp. 91-101, January 11, 2001. <http://www.itl.nist.gov/div895/docs/D-Cinema2001Proceedings.pdf>

S. Pala and E. F. Kelley, "Haze Complications in FPD Performance Reflection Measurements," SAE, 6th Annual Strategic and Technical FPD Symposium - Vehicular Applications of Displays and MEMS, Session 2 on Vehicular FPD-Requirements & Market, September 22, 1999.

E. F. Kelley, G. R. Jones, and T. A. Germer, "The Three Components of Reflection," Information Display, Vol. 14, No. 10, pp. 24-29, October 1998.

E. F. Kelley, G. R. Jones, and T. A. Germer, "Display Reflectance Model Based on the BRDF," Displays, Vol. 19, No. 1, pp. 27-34, June 30, 1998.

G. R. Jones and E. F. Kelley, "Reflection Measurement Problems Arising from Haze," 1998-SID International Symposium Digest of Technical Papers, Society for Information Display, Vol. 29, pp. 945-946, Anaheim, CA, May 17-22, 1998.

G. R. Jones and E. F. Kelley, "Bidirectional Reflectance Distribution Factor Measurements on Flat Panel Displays," Proc. CIE Expert Symposium '97 on Colour Standards for Imaging Technology, Nov 21-22, 1997, Scottsdale, AZ, publ. Commission Internationale de L'Eclairage (CIE), Vienna, Austria, pp. 28-33 (1998).

E. F. Kelley and G. R. Jones, "Utilizing the Bidirectional Reflection Distribution Function to Predict Reflections from FPDs," 1997 Society for Information Display (SID) Symposium, Digest of Technical Papers, May 11-16, 1997, Boston, MA, Sec 32.3, p. 831-834 (May 1997).

G. Jones, E. Kelley, T. Germer, "Specular and Diffuse Reflection Measurements of Electronic Displays," Society for Information Display International Symposium Digest of Technical Papers, Vol. 27, San Diego, CA, pp. 203-206, May 12-17, 1996.

E. F. Kelley and G. Jones, "Flat Panel Display Reflection Measurements at NIST," Invited Presentation at Photo Research sponsored seminar on Reflection Measurements at the EDEX'96 (Electronic Display Exhibition) in Yokohama Japan, May 1996.

TUTORIAL/OVERVIEW

M. Dowell and E. F. Kelley, "Tips for Buying Flat Panel Display Televisions," Metrologist, pp. 28, 29, January 2008.

E. F. Kelley, "Understanding Specsmanship," 2007 Display Applications Conference, Society for Information Display, Invited Paper 7.1, San Francisco, CA, October 23-25, 2007.

P. Boynton, "The Challenge to Display Metrology and Standards: Whom Do You Trust?" Digest of the IEEE Broadcast Technology Society/IBC2006, Amsterdam, September 7, 2006 (2006) (invited paper and talk)

E. F. Kelley, "Display Measurements for Flat Panel Displays," Application Tutorial A-6, Society for Information Display, 2006 International Symposium, San Francisco, California, June 9, 2006.

E. F. Kelley, "Flat-Panel-Display Measurement Techniques and Concerns," 2005-SID International Symposium, Application Tutorial, Seminar Lecture Notes, Society for Information Display, Boston, MA, May 26, 2005

P. A. Boynton, "The goals of good display metrology," The Display Standard, May 2005

E. F. Kelley, "What Do the Specifications Mean?" Proceedings of the First Americas Display Engineering and Applications Conference (ADEAC 2004), Society for Information Display, Ft. Worth, TX, USA, pp. 15-18, October 26, 2004.

P. Boynton, "The Challenge to Display Metrology and Standards: Whom Do You Trust?" Workshop and Special Evening Session of the SID 24th International Display Research Conference, pp. 46-57, August 2004.

- E. F. Kelley, "Flat-Panel-Display Measurement Techniques and Concerns," 2004-SID International Symposium Seminar Lecture Notes, Society for Information Display, Seminar F-1, Vol. 2, pp. F-1/1-61, Seattle, WA, May 28, 2004.
- P. A. Boynton, E. F. Kelley, and J. M. Libert, "Current Projects In Display Metrology At The NIST Flat Panel Display Laboratory," Fourth Oxford Conference on Spectrometry, SPIE vol. 4826 (August 2003).
- P. A. Boynton, E. F. Kelley, and J. M. Libert, "Current Projects in Display Metrology at the NIST Flat Panel Display Laboratory," Fourth CORM Oxford Conference on Spectrometry," Davidson, NC, June 9 - 13, 2002.
- E. F. Kelley, "Fundamentals of Display Metrology," 2002 Society for Information Display International Symposium Short Course S-3, 2002 SID International Symposium, Boston, Massachusetts, 205 pp., May 19-24, 2002
- E. F. Kelley, "Vehicular Display Metrology Seminar," Society for Information Display Metropolitan Detroit Chapter, 8th Annual SID Symposium on Vehicle Displays, Detroit, MI, October 16-18, 2001.
- E. F. Kelley, "Electronic Display Metrology--Not a Simple Matter," Proc. of SPIE, Vol. 4450, pp. 44-53, NIST/SPIE Centennial Symposium/Celebration, San Diego, CA, August 1, 2001.
- E. F. Kelley, "Display Metrology Seminar," Society for Information Display (SID), Metropolitan Detroit Chapter, 7th Annual SID Symposium on Vehicle Displays, Dearborn, Michigan, 18 pages (66 slides) October 3, 2000.
- P. A. Boynton, E. F. Kelley, J. M. Libert, "Meeting the Metrology Needs of the Microdisplay Industry," Proceedings of the United Engineering Foundation Microdisplay 2000 Conference, Boulder, CO, August 7-9, 2000.
- E. F. Kelley, "Flat Panel Display Measurements and Standards," Applications Seminar A-4, 2000-SID International Symposium, Society for Information Display, Long Beach, California, May 17, 2000.
- E. F. Kelley, "Electronic Display and Imaging at NIST," OIDA Advanced Electronic Imaging Workshop, SPIE Electronic Imaging Symposium & Photonics West, San Jose, CA, 38 pages, January 26, 2000.
- E. F. Kelley, "Flat Panel Display Metrology -- Less than Meets the Eye," National Conference of Standards Laboratories, Charlotte, North Carolina, July 11-15, 1999.
- E. F. Kelley, "Flat Panel Display Measurements and Standards," Applications Seminar, 1999-SID International Symposium, Society for Information Display, San Jose, CA, May 17-21, 1999.

E. F. Kelley, "Flat Panel Display Measurements and Standards," Applications Seminar, 1998-SID International Symposium, Society for Information Display, Anaheim, CA, May 17-22, 1998.

Edward F. Kelley, "Measurements for Optical Imaging Applications," Optoelectronics Metrology Roadmapping Workshop, NIST, Boulder, Colorado, February 3, 1998

E. F. Kelley, "What Is Behind Good Display Metrology?," Information Display, Vol. ?, No. ?, pp. ?, 1998.

Paul Boynton. "Flat Panel Display Laboratory at NIST". Proceedings of the Military Display Workshop, Long Branch, NJ, July 11-13, 1995. (July 1995)

P. A. Boynton, G. Jones, and E. Kelley, "Flat Panel Display Lab at NIST," abstract and viewgraphs from invited talk published in Workshop Proceedings of Third Annual Military Display Workshop, Army Research Laboratory, Appendix G-1, Jul 11-13, 1995, Ft. Monmouth, NJ (Jul 1995).

H. S. Bennett, C. Fenimore, B. F. Field, and E. F. Kelley, "Making Displays Deliver a Full Measure," Information Display, Inst. for Research Services, New York, NY, 11, Issue 1, pp. 20-27 (Jan 1995).

B. F. Field, E. F. Kelley, C. Fenimore, and H. S. Bennett, "Research on Flat Panel Display Measurements at the National Institute of Standards and Technology," Proc. Intl. Society for Optical Engineering (SPIE) Symposium on Advanced Flat Panel Display Technologies, February 7-8, 1994, San Jose, CA, SPIE Vol. 2174, pp. 30-34 (Jul 1994).

METROLOGY FOR SPECIFIC APPLICATIONS

Projection Displays

E. F. Kelley, K. Lang, L. D. Silverstein, and M. H. Brill, "Projector Flux from Color Primaries," 2009-SID International Symposium Digest of Technical Papers, Society for Information Display, San Antonio, Texas, USA, Late News Paper 17.5L, pp. 224-227, May 31 - June 5, 2009.

P.A. Boynton and E.F. Kelley, "Comparing Methodologies for Determining Resolution from Contrast in Projection Display Systems," Projection Displays XI, Proceedings of the SPIE, Vol 5740, January 2005.

P. Boynton, "Tools and Diagnostics to Assess and Improve Projection Display Metrology Capabilities," Proceedings of the First Americas Display Engineering and Applications Conference (ADEAC 2004), Society for Information Display, Ft. Worth, TX, USA, pp. 15-18, October 26, 2004

P. A. Boynton, , E. F. Kelley, and J. M. Libert "Projection Display Metrology at NIST: Measurements and Diagnostics," Liquid Crystal Materials, Devices, and Applications X and Projection Displays X, Proceedings of the SPIE, Vol. 5289, pp. 302-313, January 2004 (2004)

P. Boynton and E. Kelley, "Stray Light Elimination Tube Prototype," NIST IR 6861, March 2002

P. A. Boynton and E. F. Kelley, "Stray Light Compensation in Small Area Contrast Measurements of Projection Displays," Projection Displays VIII, Proceedings of the SPIE, Vol. 4657, pp. 122-130 (January 2002).

P. Boynton and C. Fenimore, "Characterization of Projection Systems for the MPEG-4 Digital Cinema Compression Scheme Evaluation," NIST IR 6792, 2001.

P. A. Boynton and E. F. Kelley, "Compensation for Stray Light in Projection-Display Metrology," 2001-SID International Symposium Digest of Technical Papers, Society for Information Display, Vol. 32, pp. 334-337, San Jose, CA, June 4-8, 2001.

P. A. Boynton, "Tools and Diagnostics for Projection Display Metrology," NISTIR 6591: Digital Cinema 2001 Conference Proceedings, Gaithersburg, MD, January 11-12, 2001

P. A. Boynton, E. F. Kelley, S. Highnote, R. Hurtado, "Diagnostics for light measuring devices in flying-spot display measurements," Projection Displays 2000: Sixth in a Series, Proceedings of the SPIE Vol. 3954, pp. 42-51 (2000)

P. A. Boynton, "Evaluation of Light Measuring Devices for Flying-Spot Display Measurements," Council for Optical Radiometric Measurement (CORM) Annual Conference Presentation Materials, Session IV: Optical Metrology of Displays, Gaithersburg, MD, May 3-6, 1999 (May 1999).

P. A. Boynton and E. F. Kelley, "Stray Light Elimination in Making Projection Display Measurements," Flat Panel Display Technology and Display Metrology, Proceedings of the SPIE Vol. 3636, pp. 232-239 (1999).

P. A. Boynton and E. F. Kelley, "Is the Measurement of Front-Projector Characteristics an Impossible Task?," Information Display, Vol. 14, No. 10, pp. 34-37, December 1998.

Daylight Readability

E. F. Kelley, J. Penczek, and P. A. Boynton, "Character Contrast under Uniform Ambient Conditions," 2009-SID International Symposium Digest of Technical Papers, Society for Information Display, San Antonio, Texas, USA, paper 24.1, pp. 321-324, May 31 - June 5, 2009.

S. Kim, E. F. Kelley, and J. Penczek, "Robustness of Display Reflectance Measurements: Comparison between BRDF and Hemispherical Diffuse Reflectance," 2009-SID International Symposium Digest of Technical Papers, Society for Information Display, San Antonio, Texas, USA, paper 24.2, pp. 325-327, May 31 - June 5, 2009.

E. F. Kelley, "Character Contrast," Information Display Magazine, January 2009.

J. Penczek, E. F. Kelley, and S. Kim, "Robustness of Display Hemispherical Reflectance measurement Apparatus," Invited Paper 41-1, IMID/IDMC/Asia Display 2008 Digest, pp. 1355-1357, Ilsan, Korea, October 13-17, 2008.

Edward F. Kelley, Max Lindfors, and John Penczek, "Display Daylight Ambient Contrast Measurement Methods and Daylight Readability," J. Society of Information Display, Vol. 14, No. 11, pp. 1019-1030, November 2006.

E. F. Kelley, "Daylight and Sunlight Display Readability Measurement Methods," Proceedings of the Second Americas Display Engineering and Applications Conference (ADEAC 2005), Society for Information Display, Portland, Oregon, USA, pp. 1-4, October 25-27, 2005.

Medical Displays

A. Saha, E. F. Kelley, and A. Badano, "Accurate color measurement methods for medical displays," Med. Phys., Vol. 37, No. 1, January 2010, to be published.

Anindita Saha, Hongye Liang, Aldo Badano, and Edward F. Kelley, "Accurate color measurement methods for medical displays," SPIE Medical Imaging, Conference 6516 PACS and Imaging Informatics, San Diego, CA, USA, 17-22 Feb. 2007.

Edward F. Kelley, Paul A. Boynton, and John M. Libert, "Evaluation of Luminance Probes Used for Accurate Contrast Measurements in Medical Displays," Council for Optical Radiation Measurements Conference, Stanford University, Menlo Park, California, June 19-20, 2003.

A. Badano, S. Pappada, E. F. Kelley, M. J. Flynn, S. Martin, and J. Kanicki, "Luminance probes for contrast measurements in medical displays," 2003-SID International Symposium Digest of Technical Papers, pp. 928-931, Society for Information Display, Baltimore, MD, May 18-23, 2003.

First-Responder Imaging Cameras

Joshua B. Dinaburg, Francine Amon, Anthony Hamins, Paul Boynton, "Performance of liquid-crystal displays for fire-service thermal-imaging cameras," Journal of the Society for Information Display, June 2008 (2008).

Joshua B. Dinaburg, Francine Amon, Anthony Hamins, Paul Boynton, "LCD display screen performance testing for handheld thermal imaging cameras" Proceedings of SPIE, the International Society for Optical Engineering, Infrared imaging systems (design, analysis, modeling, and testing XVII) (19-20 April, 2006) (2006)

Microdisplays

P. A. Boynton, "Microdisplay Metrology Research at NIST," Proceedings of the Scottish Optoelectronics Association (SOA) / Society for Information Display (SID) Conference and Workshop on Microdisplays and Their Applications, Edinburgh, UK, September 13-14, 2001

P. A. Boynton, E. F. Kelley, J. M. Libert, "Meeting the Metrology Needs of the Microdisplay Industry," Proceedings of the United Engineering Foundation Microdisplay 2000 Conference, Boulder, CO, August 7-9, 2000.

Viewing Angle

T. G. Fiske, L. D. Silverstein, C. Penn, E. F. Kelley, "Viewing Angle: A Matter of Perspective," 1998-SID International Symposium Digest of Technical Papers, Society for Information Display, Vol. 29, pp. 937-940, Anaheim, CA, May 17-22, 1998.

Noise Perception

Stephen Herman, Bruce Field, Paul Boynton, and Gerard de Haan. "The Perception of Clamp Noise in Television Receivers." Conference Record of the Society for Information Display International Display Research Conference, Monterey, CA, October 10-13, 1994, pp. 317-320 (Oct 1994).

Stephen Herman, Bruce Field, and Paul Boynton, "Quantification of Temporal Noise Threshold in Television Displays", Society for Information Display International Symposium Digest of Technical Papers, San Jose, CA, June 14-16, 1994, vol. XXV, pp. 869-872 (May 1994)

Modeling

Edward F. Kelley, Bruce Field, George R. Jones, and Paul A. Boynton, "Display Modeling and Active Matrix Liquid Crystal Display Model on a Video Supercomputer," Society for Information Display International Symposium Digest of Technical Papers, Vol. 25, pp. 779-782, San Jose, CA, June 14-16, 1994.

Appendix C. FPDM Standard Economic Impact Survey Instrument

Survey FPDM Standard (1.0, 2.0) Economic Impact

Introduction

NIST is conducting an impact assessment of a documentary standard. NIST has conducted numerous economic impact assessments over the years. For examples of such assessments, go to < http://www.nist.gov/director/planning/study_info.cfm>.

Survey respondents were chosen as the survey population because of their interest and familiarity with the subject matter and their first-hand knowledge of the documentary standard development process.

The Flat Panel Display Measurement (FPDM) standard (FPDM 1.0 and FPDM 2.0), (developed by the FPDM Working Group of the Video Electronics Standards Association (VESA)) has been selected as the basis for this assessment of documentary standards. The choice of FPDM has no strategic significance. It was deemed the best candidate of a small number of projects from an impact assessment perspective.

BECAUSE THIS SURVEY CONCERNS THE PAST, AND BECAUSE WE ARE SENSITIVE TO THE BURDEN PLACED ON INDUSTRY RESPONDENTS, WE ARE NOT SEEKING "ACCOUNTING QUALITY" ANSWERS. WE EXPECT ROUGH-ORDER-OF-MAGNITUDE ANSWERS BASED ON YOUR SEASONED JUDGEMENT; ESTIMATES THAT WOULD "MAKE SENSE" TO OTHER EXPERIENCED INDUSTRY PARTICIPANTS GIVEN THE TIME CONSTRAINTS OF 30 MINUTES OR SO.

TASC Inc., an independent analytical services company, is conducting this assessment on NIST's behalf. All the answers you provide will be held in the strictest confidence. **All data in the economic impact assessment will be reported in aggregated form, as averages and ranges, so that no individual person, company, or establishment data will be discernable.**

The impact assessment will be based on data collected for this survey and employs a present discounted value approach to organizing time series estimates of benefits and costs provided by you, the survey respondents. The data will be compiled to calculate several measures of economic impact.

We need you to provide your best estimates to all questions. Where these take you past your comfort zone, consider that there is likely no one in a better position to formulate a response. If, in addition to your response, you would like to suggest a point of contact within your organization whose estimate we would also benefit from obtaining, please provide us with a name, phone number, and e-mail address. We will contact that person and solicit their estimates as well. We welcome this opportunity.

As a token of appreciation for participating in this survey effort, the final report will be available from NIST in early 2011 and you and your company will be listed in the acknowledgements. Your full participation in the survey assures that the report will be based on the best information available.

NOTE: This survey contains collection of information requirements subject to the Paperwork Reduction Act. Notwithstanding any other provision of the law, no person is required to respond to, nor shall any person be subject to a penalty for failure to comply with, a collection of information subject to the requirements of the Paperwork Reduction Act, unless that collection of information displays a currently valid OMB control number. The estimated response time for this survey is 30 minutes. The response time includes the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information." OMB Number: 0693-0033; Expiration: 10/31/2012.

Background Information

1. The flat panel display industry consists of multiple tiers or facets. Please indicate the industry tiers that best characterize your company's role in the industry.

- End user** (e.g., general or professional consumer)
 - Original equipment manufacturer** (e.g., Dell, Sun Microsystems, HP, Apple, Sony, Samsung *or* Boeing, Lockheed-Martin, Raytheon, Northrop-Grumman)
 - Display Manufacturers** (e.g., Samsung, LG, AUO, CMO, CPT, HannStar *or* aerospace display manufacturers such as Honeywell, Rockwell-Collins, American Panel Corp.)
 - Display component/material manufacturers**
 - Equipment manufacturers (including measurement instruments)**
 - Testing laboratories**
 - Other** (Please specify and offer an explanation of your role.)
-

2. For the segment(s) of the tier(s) of the FPD industry in which your company operates, please estimate your company's average annual shares - of the *worldwide market* and *U.S. market* for products and services that are significantly affected by FPDM - over time for each of two periods—1992-1998 and 1999-2007.

	1992-1998	1999-2007
For Worldwide Sales:		
Average Annual Company Share (%)		
For U.S. Sales:		
Average Annual Company Share (%)		

Please provide explanatory notes about your market segment(s) and tier(s) if necessary:

3. What facets of your company's operations are most affected by the measurement data and techniques represented in the FPDM.

- R&D**
 - Qualification of displays for use in complementary products/services**
 - Manufacturing process quality control**
 - Acceptance testing**
 - Complaint adjustment**
 - Other** (Please specify and explain for a non-expert.)
-

4. In what year did your company adopt FPDM as its measurement standard?

FPDM 1.0

FPDM 2.0

Costs and Benefits Estimates

FPDM Working Group Participation

For the purposes of this assessment, VESA's FPDM Working Group was constituted in 1992 and continued through 2007 (when the Working Group's activities were transferred to SID's, ICDM). In the analysis of survey data, we will distinguish two periods, 1992-1998 (that includes the release of FPDM 1.0 in 1998) and 1999-2007 (that includes the release of FPDM 2.0 in 2001).

5. Estimate the average annual number of hours your company employees or consultants actually dedicated to the FPDM Working Group, 1992-2007.

Average Annual Hours, 1992-1998:

Average Annual Hours, 1999-2007:

6. In 2010 dollars, estimate the value of the fully burdened (i.e., including benefits such as retirement and health) annual compensation for a full-time equivalent (FTE) employee with the requisite expertise to participate in the efforts of the FPDM Working Group.

Total annual compensation for one FTE in 2010 dollars: \$

Absent FPDM

Economic impact assessments are often conducted on the basis of a "counterfactual scenario" that posits how things would have been in the absence of the event being assessed. Prior to the release of FPDM 1.0, producers or buyers of flat panel displays would consult any (or all) of a number of existing standards (depending on the specific application) and develop their own methodologies for assessing display quality, often in consultation and coordination with their suppliers and buyers.¹⁰⁷

107. According to an authoritative source, the following standards were available for consultation: ISO 9241 (Parts 3, 7, 8) and ISO 13406 (draft 2); ANSI HSF-100 (1988) and IT7.215 (1992); EIA TEB (27) and TEP (105); VESA Display Specifications and Test Procedures (for CRTs); NIDL's Procedures for Evaluation and Reporting the Capabilities of High Performance Display Monitors for Imagery Applications; SAE ARP 1782 and ARP 4260; MRP 1990:8 (1990:10); USAF AFGS 87213A; and IEC SC 47C. Consulting these various uncoordinated standards presented measurement difficulties because they described what a flat panel display was to perform, not how it was to be tested; the various standards were not aligned for any specific purpose; they provided only partial solutions to characterization, specification, or qualification tasks and required the buyer and/or supplier to develop consolidated and integrated proprietary specifications and qualifications; often provided inadequate measurement methods; and often

For evaluation purposes, we posit a counterfactual scenario with two phases labeled, "do-it-yourself" and "find another home."

7. For the period 1992-1998 (release of FPDM 1.0, 1998) estimate the average annual number of hours expended by your company (and, in parenthesis, its suppliers and buyers) in "do-it-yourself" solutions to problems and issues for which the information in FPDM 1.0 provided an alternative solution.

Average Annual Hours, 1992-1998: (Suppliers/Buyers Hours:)

Please provide some typical examples of the types of problems and issues you have in mind in your response to *Question #7*.

8. In 2010 dollars, estimate the value of the fully burdened (i.e., including benefits such as retirement and health) annual compensation for a full-time equivalent (FTE) employee with the requisite expertise to develop "do-it-yourself" solutions to problems and issues for which the information in the FPDM provided alternative solutions.

Total annual compensation for one FTE in 2010 dollars \$

9. Please identify an organization ("another home") that, in your view, would likely have developed an alternative to FPDM, had VESA not undertaken the effort, and the year the FPDM alternative would have emerged in that scenario.

Alternative organization:

Year an FPDM alternative would have emerged:

Effectiveness of that FPDM alternative (% of FPDM quality): %

If you would like to elaborate, please provide your rationale for the three responses:

assumed that measurement techniques for older technologies (e.g., CRTs) transferred well to new technologies (e.g., LCDs). See, Edward F. Kelley, George R. Jones, Paul A. Boynton, Michael D. Grote, and Dennis J. Bechis. "A Survey of the Components of Display Measurement Standards," *Journal of the Society for Information Display*, Vol. 3, No. 4, December 1995, pp. 219-222.

10. For the period from the time that your company adopted FPDM 1.0 until the time that it adopted FPDM 2.0—indicated in your answer to *Question #4*—estimate the average annual number of hours expended by your company (and, in parenthesis, its suppliers and buyers) in “do-it-yourself” solutions to problems and issues not addressed in FPDM 1.0 but for which FPDM 2.0 did provide solutions.

Average Annual Hours, from adoption of FPDM 1.0 until adoption of FPDM 2.0:
(Suppliers/Buyers Hours:)

Please provide some typical examples of the types of problems and issues you have in mind in your response to *Question #10*.

11. After the organizational change from VESA to SID in 2007, development of the forthcoming ICDM Display Measurements Standard (DMS) began. The new ICDM DMS is expected to enable more do-it-yourself cost avoidance, because it will include standard performance measurements in FPDM and hence the resulting do-it-yourself cost avoidance, but also there will be development of the standard, extending coverage to measurements not covered in FPDM, allowing even more substitution for do-it-yourself activities. The do-it-yourself cost-avoidance will be what was obtained with FPDM and then more. Moreover, the new ICDM DMS is expected to accomplish in new ways some of the measurements that FPDM substituted for do-it-yourself solutions. To the extent that new ICDM DMS procedures are substituted for previously existing FPDM procedures, some of the do-it-yourself cost-avoidance that had been due to FPDM would be due to the new ICDM DMS. The question here is what percentage of the previous do-it-yourself cost-avoidance from FPDM is still anticipated to be obtained from the content of FPDM rather than having been replaced by new content in ICDM DMS. The answer could be close to 100%, or if the ICDM DMS is expected to substitute new approaches for much of what is in FPDM 1.0 and 2.0, the answer could be substantially less than 100%.

11a. What percentage of the benefits (the costs avoided in do-it-yourself solutions) realized by your company because of FPDM do you anticipate will still be realized and still be due to the content of FPDM rather than the new content in ICDM DMS?

Percentage of benefits due to FPDM:

< 10% 10%-20% 21%-30% 31%-40% 41%-50%

51%-60% 61%-70% 71%-80% 81%-90% >90%

11b. What do you anticipate to be the commercial lifetime (in years) of the forthcoming ICDM Display Measurement Standard (DMS)?

Years

Benefits of NIST Participation in the FPDM Working Group

12a. Given your answers to Question #5, estimate the average annual additional (beyond those reported in Question #5) number of hours your company employees or consultants would have dedicated to the FPDM Working Group, 1992-2007, had NIST *not* participated in the effort and each of the Working Group participants cooperatively increased their time dedicated to the effort to the extent needed to ensure the quality and the same time of development of the existing FPDM.

Average Annual *Additional* Hours, 1992-1998:

Average Annual *Additional* Hours, 1999-2007:

12b. Estimate the years that FPDM 1.0 (1998) and FPDM 2.0 (2001) *would have been released, if NIST had not participated* in the effort *and* the average annual number of hours your company employees or consultants (and other participants) dedicated to the FPDM Working Group *remained the same* as provided in your response to Question #5.

“Absent NIST” FPDM 1.0 release year:

“Absent NIST” FPDM 2.0 release year:

Thank you for taking the time to provide your best estimates for the answers to the questions.

We look forward to providing you with the results of our analysis.

Appendix D. Economic Impact Metrics¹⁰⁸

The economic impact metrics in this report are calculated from a time series of costs and benefits in constant dollars. They represent "real" rates of return. In contrast, "nominal" rates of return would be based on time series of current dollars (the dollars of the year in which the benefits were realized or the costs were incurred).

Social Rate of Return (SRR)

The SRR is the value of the discount rate, i , that equates the net present value (NPV) of a stream of all net benefits associated with an investment project to zero. The time series runs from the beginning of the project, $t = 0$, to a milestone terminal point, $t = n$. Net benefits refer to total benefits (B) less total costs (C) in each time period. Mathematically,

$$(1) \text{ NPV} = [(B_0 - C_0) / (1 + i)^0] + \dots + [(B_n - C_n) / (1 + i)^n] = 0$$

where $(B_t - C_t)$ represents the net benefits associated with the project in year t , and n represents the number of time periods (years in most cases) being considered in the evaluation.

For unique solutions of i , from equation (1), the SRR can be compared to a value, r , that represents the opportunity cost of funds invested by the technology-based public institution. Thus, if the opportunity cost of funds is less than the social rate of return, the project was worthwhile from an ex post social perspective.

Benefit-to-Cost Ratio

The ratio of benefits-to-costs is precisely that, the ratio of the present value of all measured benefits to the present value of all costs. Both benefits and costs are referenced to the initial time period, $t = 0$, as:

$$(2) B / C = [\sum_{t=0 \text{ to } t=n} B_t / (1 + r)^t] / [\sum_{t=0 \text{ to } t=n} C_t / (1 + r)^t]$$

A benefit-to-cost ratio of 1 implies a break-even project. Any project with $B / C > 1$ is a relatively successful project. Fundamental to implementing the ratio of benefits-to-costs is a value for the discount rate, r .

While the discount rate representing the opportunity cost for public funds could differ across a portfolio of public investments, the calculated metrics in this report follow the

¹⁰⁸ The characterization of the three metrics follows A. Link and J. Scott, *Public Accountability: Evaluating Technology-Based Institutions* (Boston: Kluwer Academic Publishers) 1998.

guidelines set forth by the Office of Management and Budget: Constant-dollar benefit-cost analyses of proposed investments and regulations should report net present value and other outcomes determined using a real discount rate of 7 percent.¹⁰⁹

Net Present Value (NPV)

The information developed to determine the benefit-to-cost ratio can be used to determine net present value as:

$$(3) \text{ NPV} = B - C.$$

¹⁰⁹ Office of Management and Budget (OMB), Circular No. A-94 Revised, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs," October 29, 1992.