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A Case Study:

The Economic Benefits of NIST's Role in Security Standards Development: X-Ray Standards for Bulk-Explosives Detection

Standards Coordination Office

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The Economic Benefits of NIST's Role in Security Standards Development: X-Ray Standards for Bulk- Explosives Detection

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Introduction

Following the terrorist attacks of September 11, 2001, the U.S. government, and its political allies, launched a series of efforts to up-grade their most vulnerable infrastructural systems. Not the least of these was the air transportation system.The following descriptive case study is intended to provide a concrete example of how one specific suite of security standards — x-ray standards for bulk-explosives detection — enhanced the physical security of air transportation for passengers and cargo alike and created economic value in the process. This case focuses on the benefits that were created by NIST's engagement in the standards development process; economic benefits that accrued to x-ray equipment manufacturers, equipment buyers (public and commerical), and aviation services users. Experience shows that standards, and their underlying measurement technology, create economic value in a myriad of ways.

The story of how benefits are created in this case is depicted in Figure 1. In response to the stark reality of terrorism, DHS, NIST, their international counterparts, and private sector x-ray equipment manufacturers, worked together to develop the scientific and technical basis for explosives detection. The result was the development, renovation, and promulgation of x-ray safety and image performance consensus standards that have contributed significant benefits to users of air transportation services, government procurement agencies, private sector equipment manufacturers, and to the international community that shares a safer air transportation infrastructure.

Figure 1. X-Ray Screening Standards Value Creation Process

In the following, two facets of the value chain for x-ray screening — airport and air cargo — are distinguished; their respective infrastructures are described; and the scope of economic impacts that flow from the development of the supporting consensus standards are characterized.

In 2001 the international community found itself with no comprehensive standards for the technical performance of x-ray or gamma-ray security-screening equipment, and, with the increasing focus on using such technologies for homeland-security applications, there was obvious need for criteria against which the performance of these technologies could be evaluated. It was this shortfall that formed the basis for the need for this activity. Since September 11, 2001 U.S., legislation has transformed the global air transportation system. Several public laws have driven U.S. agencies to revolutionize the provision of aviation security and caused the development of x-ray security standards for bulk-explosives detection.[1] In turn, these security standards have helped to transform the aviation x-ray screening infrastructure. The *National Strategy for Homeland Security* (2002) identified the need for standards to support homeland security and emergency preparedness.

Following the October 2010 discovery of two explosive devices being prepared for loading on overseas U.S.-bound all-cargo aircraft, renewed policy debate over air cargo security measures prompted some policymakers to call for comprehensive screening of all air cargo, including shipments that travel on all-cargo aircraft. There has been considerable interest in increasing international cooperation with respect to air cargo security, screening, and inspection methods. The Transportation Security Administration (TSA) has entered into agreements with the European Union, Canada, and Australia, and is working with the International Civil Aviation Organization (ICAO) to draft worldwide standards for air cargo security.[2]

The nation's air, land, and marine transportation systems are designed for accessibility and efficiency, two characteristics that make them highly vulnerable to terrorist attack. Since the system of air travel is an international system whose nodes extend beyond our borders into the geographical space of other nations, security concerns and actions by one nation can result in significant costs and benefits for other nations. These spillover costs and benefits provide the economic justification for strong government cooperation.[3]

Two Facets of X-Ray Standards: Air Travel and Air Cargo Screening

While it is generally understood that standards, and the breadth of their application, have net positive consequences, the examination of a specific case is intended to focus on the ways in which security standards create value. The literature on the economic benefits of standards is broad. The case study, in a manner of speaking, shows "where the rubber meets the road."

As narrow an example as x-ray screening equipment may appear to be, x-ray equipment for rail, waterborne, and air cargo, on the one hand, and airport screening equipment, on the other hand, are quite different businesses. To some extent the differences in the equipment and the markets are due to the different purposes the equipment serves and different institutions that perform equipment acquisition.

1. Important laws with a bearing on x-ray screening include: *The Aviation and Transportation Security Act (ATSA)* (November 2001) which established the Transportation Security Administration (TSA); *The Intelligence Reform and Terrorism Prevention Act of 2004; The Homeland Security Appropriations Act of 2005*; *The Implementing the 9/11 Commission Recommendations Act of 2007*; and *The Air Cargo Security Act (introduced in 2010).* For the implications of these laws for air transportation x-ray screening, see Bart Elias, *Airport Passenger Screening: Background and Issues for Congress*, Congressional Research Service, April 23, 2009; and *Screening and Securing Air Cargo: Background and Issues for Congress*, Congressional Research Service, December 2, 2010.
2. Bart Elias, *Transportation Security: Issues for the 112th Congress*, Congressional Research Service, 2011.
3. Cletus C. Coughlin, Jeffrey P. Cohen, and Sarosh R. Khan "Aviation Security and Terrorism: A Review of the Economic Issues," *Review,* Federal Reserve Bank of St. Louis, September/October, 2002.

The U.S. Airport and Air Cargo X-Ray Screening Value Chain

The U.S. airport and air cargo x-ray screening value chain is depicted in Figure 2, with value increasing from bottom to top. At the top of the value chain, air traveling passengers and cargo are more secure because of x-ray screening processes. Those processes, in turn, are implemented in part by the procurement and operation of x-ray screening equipment that is certified (on the passenger side) and qualified (on the cargo side), prior to installation, and periodically tested and audited, after installation, by the TSA with the support of the Transportation Security Laboratory (TSL). (This dual role accounts for the presence of the TSA and TSL at two levels in the value chain depicted in Figure 2. The feedback loops indicate other TSA/TSL (and NIST) interactions.) The TSA utilizes image performance and safety standards (discussed below) in its certification/qualification requirements. These consensus standards are developed through the participation of TSL, industry, NIST, and public and private sector researchers in national and international standards development organizations (SDOs). Equipment manufacturers develop and sell equipment used to screen passengers, their baggage, and cargo. NIST develops or facilitates the development of measurement protocols and test artifacts that are used by manufacturers and others to develop, test, and verify x-ray screening equipment performance. NIST conducts research, radiation-transport calculations, and field-testing in support of these efforts as well as following and supporting R&D in relevant fields.

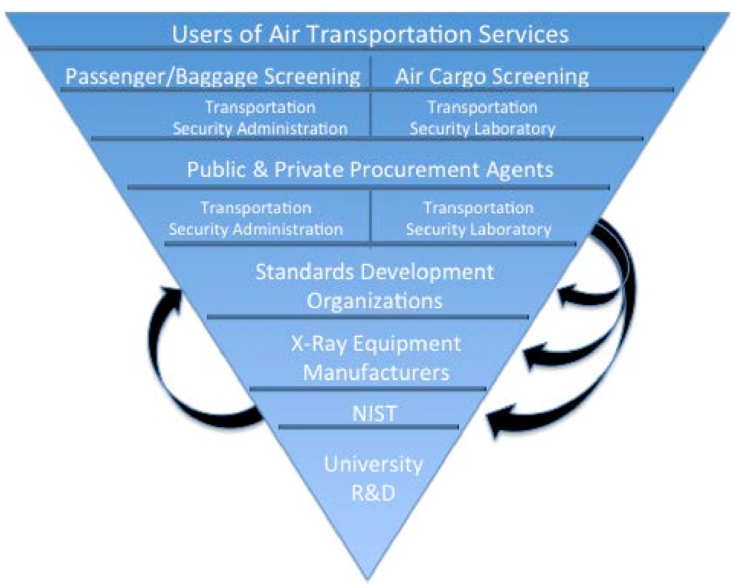

Figure 2. X-Ray Screening Value Chain

X-Ray Screening Infrastructure

Air Passenger Infrastructure. The second layer from the top of the x-ray screening value chain depicted in Figure 2 contains the infrastructure of processes with which air travelers are familiar. They are largely unfamiliar with the supporting layers of the underlying value chain. There are over18,000 airports in the U.S. More than 3,000 of these are eligible to receive federal funding. Passenger and carry-on luggage screening is conducted at more than 450 airports (designated as “primary” airports), and checked baggage is screened at approximately 460 commercial airports throughout the United States. There are more than 750 screening checkpoints and more than 2,000 screening lanes at the nation’s commercial airports. During 2010, TSA introduced whole body imaging (WBI) systems (also known as Advanced Imaging Technology (AIT)) at airport checkpoints around the United States.[4] TSA has deployed nearly 500 such machines at domestic airports throughout the country and has procured and deployed an additional 500 AIT units using FY11 funds for a total of 1,000 AIT units. This will allow an estimated 60 percent of the passengers to be screened using this technology. An additional 275 AIT units are planned in the FY2012 budget, bringing the total coverage to 1,275 AIT units providing coverage to 80 percent of passengers.[5]

In 2006, the TSA reported that it had screened over 700 million passengers and other individuals accessing the secured areas of airports in the United States. If airline passenger traffic grows as predicted, then the TSA will likely be screening over one billion people annually by 2024. [6] Average peak wait times at screening checkpoints FY2004-FY2006, was approximately 10 to 15 minutes, depending on airport category.[7]

TSA deploys explosives detection systems (EDS) and explosives trace detection (ETD) machines to screen all checked baggage transported by U.S. and foreign air carriers departing from U.S. commercial airports. Typically, ETDs are used for primary screening of checked baggage at smaller airports.[8] As of October 2010, TSA had 2,297 EDS machines in its fleet, 1,938 of which were deployed at airports in the United States. As of February 2011, TSA estimated that there were about 5,200 ETD machines used for the primary or secondary screening of checked baggage at U.S. commercial airports.[9]

The use of security scanners and WBIs at airports is increasing worldwide. Nevertheless, their use within the EU is regulated at national level by applying different national standards. On the other hand serious risks of undermining fundamental citizen rights (e.g. privacy, free movement, health concerns, etc.) could appear when WBI technologies are deployed.[10]

Air Cargo Infrastructure.[11] The air cargo industry consists of a complex distribution network linking manufacturers and shippers to freight forwarders, off-airport freight consolidators, and airport sorting and cargo handling facilities where shipments are loaded and unloaded from aircraft.[12] Typically, shippers have no foreknowledge of the particular route or aircraft by which a package will be transported. Freight forwarders and airlines make such determinations to optimize the flow of air cargo. Cargo placed on aircraft travels both domestically and internationally. By value, airfreight accounted for 25.1 % of the value of commodities shipped as

4. Bart Elias, *Transportation Security: Issues for the 112th Congress*, Congressional Research Service, 2011.
5. TSA Security Operations and Technology Deployments, TSA Testimony, June 2, 2011..
6. Bart Elias, *Airport Passenger Screening: Background and Issues for Congress*, Congressional Research Service, April 23, 2009.
7. TSA classifies airports into one of five categories (X, I, II, III, and IV) based on various factors, such as the total number of takeoffs and landings annually, the extent to which passengers are screened at the airport, and other special security considerations. In general, category X airports have the largest number of passenger boardings, and category IV airports have the smallest. See, *TSA Has Made Progress but Faces Challenges in Meeting the Statutory Mandate for Screening Air Cargo on Passenger Aircraft*, USGAO, June 2010, (GAO-10- 446).
8. ETDs do not employ x-ray technology and are not further discussed.
9. *TSA Has Enhanced Its Explosives Detection Requirements for Checked Baggage, but Additional Screening Actions Are Needed*, USGAO, July 2011, (GAO-11-740).
10. This issue is further discussed below. See the section entitled, “Public Concerns.”
11. This section relies on Bart Elias, *Screening and Securing Air Cargo: Background and Issues for Congress*, Congressional Research Service, December 2, 2010.
12. Shippers are the owners of air cargo items and may be either individuals or businesses. Freight forwarders are brokers or middlemen that do not operate aircraft, but make arrangements for moving cargo and may operate distribution centers that store incoming shipments and then send them on to final recipients. Since freight forwarders do not operate aircraft, but provide air cargo services, they are referred to in regulation as indirect air carriers (IACs).

freight in 2007. Most outbound air cargo packages are consolidated at off-airport facilities and arrive at airports on bulk pallets or in special containers known as unit load devices. It is estimated that about 75% of all air cargo travels on bulk pallets. Most international air cargo that enters the United States transits through large hub facilities in Europe and Asia.

Approximately 19 billion pounds of cargo were shipped on domestic flights in 2009. Of this, FedEx transported more than 10 billion pounds and UPS carried more than 5.5 billion pounds. Collectively, these two carriers transported about 83 % of all domestic air cargo in 2009, and were by far the largest two operators in the U.S. air cargo industry. Additionally, in 2009, approximately 15.7 billion pounds of international air cargo were transported to and from the United States. FedEx and UPS, combined, transported only about 15 % of international air cargo to and from the United States reflecting the greater number and diversity of air carriers that transport cargo that originates overseas. Passenger aircraft play a much greater role in transporting air cargo internationally than within the United States. On international routes, roughly one-third of air cargo by weight is transported on passenger aircraft, compared to only 7 % in domestic markets.

Screening pallets and containers can be complex, time consuming, and costly, potentially requiring the shipments to be broken down so that individual items can be examined. The TSA's Certified Cargo Screening Program (CCSP) is intended to minimize these logistical complexities by allowing screening to occur at factories, warehouses, third party logistics providers, and off-airport cargo consolidation facilities, so long as the operator of the facility tenders cargo to either an air carrier or a freight forwarder. The CCSP program is voluntary. TSA must approve the screening procedures of applicants as well as supply chain security measures to prevent tampering with shipments once they have been screened, TSA audits participants' performance. To indicate the scale of this facet of the air transportation industry, TSA anticipated vetting almost 275,000 cargo handlers and other supply-chain employees covered under CCSP in FY2011, over and above the 200,000 employees at CCSP facilities that had already completed security threat assessments in FY2010. By late August 2010, over 1,000 facilities—including more than 500 indirect air carrier facilities, almost 100 independent cargo screening facilities, and almost 400 shippers—had been certified under the CCSP program. These totals represent only a fraction of the domestic air cargo industry.

TSA has regulatory oversight with regard to air cargo security matters of about 4,400 freight forwarders, about 300 air carriers, and more than 1,000 facilities that are participating in the CCSP. TSA has about 500 transportation security inspectors overseeing the air cargo sector, more than double the cargo inspector workforce in FY2006. TSA has 10 international cargo transportation security inspectors deployed to field offices in Los Angeles, Dallas-Fort Worth, Miami, and Frankfurt, Germany to examine cargo operations at the last points of departure to the United States and assess compliance with screening and security requirements. Additionally, TSA has eight international industrial representatives who work with about 240 foreign passenger and all-cargo air carriers that operate flights to the United States. These individuals have responsibility for ensuring foreign air carrier compliance with TSA regulations, including those pertaining to the screening and security of air cargo.

RDT&E Infrastructure: Government and Industry

Under its mandate the TSA certifies the x-ray screening equipment it deploys to commercial airports for screening passengers, their carry-on luggage and checked baggage. These equipment certifications are based on tests performed by the TSL. Specifically, TSA certifies that screening equipment can detect the amounts, configurations, and types of explosive material that would be likely to be used to cause catastrophic damage to an aircraft. The requirements for these systems are developed in consultation with experts from outside TSA. TSA periodically reviews threats to civil aviation security, including explosive materials that present the most significant threat to civil aircraft; the minimum amounts, configurations, and types of explosive material that could cause catastrophic damage to aircraft in air transportation; and the amounts, configurations, and types of explosive material that can be detected reliably by existing or near-term explosive detection technologies.[13]

TSA requires that screening equipment undergo three types of testing: certification testing, integration testing, and operational testing. First, TSA verifies that vendors' equipment is capable of meeting TSA's explosives detection requirements through the certification testing process. The TSL conducts independent test and evaluation of screening equipment. Prior to certification testing, TSL conducts preliminary evaluations, known as certification readiness testing (CRT) and pre-certification. TSL provides feedback to vendors on their equipment's strengths and weaknesses in detecting explosives in order to help vendors make necessary adjustments. Second, in addition to being certified, screening equipment being deployed in an in-line configuration must also undergo integration testing to demonstrate, in a controlled environment, that they can be successfully integrated within existing screening and detection systems. Finally, following certification and integration testing, equipment undergoes operational testing in an airport setting to demonstrate that they can reliably and effectively function in a live airport environment.[14]

In 2005, NIST and DHS launched an effort to develop a suite of national voluntary consensus standards that span the use of x-rays and gamma rays in the screening of carried items and human subjects at airline checkpoints, airline checked baggage, air cargo, and other venues, as well as the associated radiation safety concerns.[15,16] Table 1 indicates the nature and timing of the x-ray safety and measurement standards that emerged from the effort.[17]

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13. *TSA Has Enhanced Its Explosives Detection Requirements for Checked Baggage, but Additional Screening Actions Are Needed*, USGAO, July 2011, (GAO-11-740).
14. Ibid.
15. Larry Hudson, Steve Seltzer, Paul Bergstrom, and Frank Cerra, "In God We Trust, X-Ray Everything Else! Standards for X-Ray and Gamma-Ray Security Screening Systems," *DSP JOURNAL*, July/December, 2007.
16. In the 2002-2006 period, NIST was also intensively engaged with DHS in the "fast-track" development of radiation instrumentation standards through IEEE/ANSI's N42 National Committee on Radiation Instrumentation See, Erik Puskar and David Leech, "Bottom-Line Impact: the Economic Value of Documentary Standards," *ISO Focus+*, Vol. 1, No. 6, June 2010, ISO Central Secretariat; and Erik Puskar *Selected Impacts of Documentary Standards Supported by NIST 2008 Edition* (NISTIR 7548), National Institute for Standards and Technology, January 2009, pp. 23-28.
17. Safety and technical performance standards for portable x-ray sources used by bomb squads were also part of the suite of standards that emerged but these are not considered in this case study. These include NIJ 0603.01 and ANSI N42.55 — draft (*American National Standard for the Performance of Portable X-Ray Systems for Use in Bomb Identification*), for portable source technical performance, and ANSI/HPS N43.3-2008 for portable source radiation safety.

Table 1. U.S. & International X-Ray Standards for Bulk Explosives Detection

Venue	Technical Performance	Radiation Safety
Checkpoint	ANSI N42.44 – 2008 ASTM F792 – 2008	ASTM F 1039; W2002 (21 CFR 1020.40)
CT / EDS **(Checked Luggage)**	ANSI N42.45-2011	ASTM F1039; W2002 (21 CFR 1020.40)
Whole Body Imaging **(AIT)**	ANSI N42.47 – 2010 IEC 62709 – CD2	ANSI/HPS N43.17 – 2009 IEC 62463 – 2010
Cargo / Vehicle	ANSI N42.46 – 2008 IEC 62523 – 2010 ANSI N42.41 – 2007	ANSI N43.16 – draft IEC 62523 – 2010 ANSI N43.14 – 2011
All Venues	N/A	ANSI/HPS N43.3-2008 ANSI/ANS 6.1.1-1991; W2001 (29 CFR 1910)

These standards have evolved as TSA requirements have evolved.[18] The process of defining a security standard as been characterized as a "virtuous circle" depicted in Figure 3. It usually begins with a group of stakeholders who identifying aspects of imaging performance that would be relevant to a particular venue of x-ray screening (e.g., aviation security, schools, prisons, courthouses, etc.) and how that performance will be measured. This is done with an eye toward known threats, technical capabilities, and TSA threat-based requirements. Sometimes the standards push vendors to do better and, sometimes, evolving measurement capabilities (or evolving threats) push the standards to be more demanding. In the case of x-ray imaging applications, the process has produced standard artifacts that guage such metrics as resolution, useful penetration, and materials discrimination. With well-defined test methods and well-specified test objects, test & evaluation procedures allow the comparison of x-ray screening system models. Well-defined test methods and test objects also allow x-ray screening system users to assess the relative strength and weaknesses of various manufacturers' equipment and to assess that equipment, in use, over time as systems age or are upgraded. For example, ANSI N42.45-2011 is one component of TSA's comprehensive verification and certification process for automated explosive detection systems. The basis for specifying and quantifying the connections between a screening system's image quality performance and its ability to detect a threat has not yet been established in a scientific sense, but the recent development and implementation of the well-defined test methods and test objects that underlie the newest x-ray

18. TSA first revised its explosives detection requirements in November 2005, updating requirements that had been established in 1998 by the Federal Aviation Administration. In January 2010, TSA again revised the explosives detection requirements and plans to deploy EDSs meeting these requirements in a tiered and phased approach over a number of years. TSA is in the process of developing another tier of requirements, which will refine the amount (for example, minimum mass) of an explosive that can cause catastrophic damage to an aircraft. *TSA Has Enhanced Its Explosives Detection Requirements for Checked Baggage, but Additional Screening Actions Are Needed*, USGAO, July 2011 (GAO-11-740).

standard for bulk explosives are a necessary first step and, some experts believe, quite beneficial.[19]

Figure 3. The "Virtuous Circle" Process of Security Standards Development

In some cases the security standard calls out minimally acceptable requirements to aid users who have less sophisticated test capabilities than, for example, TSA's TSL. ANSI N42.44, for checkpoint x-ray systems, has applications beyond aviation security, for schools, prisons, courthouses, etc. Its minimal requirements will evolve over time to reflect evolving threats or technical capabilities. Although the TSL has more demanding (and classified) requirements than the minimally acceptable ones, they still use the ANSI N42.44 test object and test method in their verification and certification process.

In the U.S., national consensus radiation safety standards related to security-screening x-ray systems are published by the American National Standards Institute (ANSI) Accredited Standards Committee N43, *Equipment for Non-Medical Radiation Applications.* The N43 committee is administered by the Health Physics Society (HPS). TSA has required that any backscatter and/or forward-scatter x-ray systems approved for deployment in U.S. airports conform to the standard: ANSI/HPS N43.17-2009, *Radiation Safety for Personnel Security Screening Systems Using X-Ray or Gamma Radiation*. This standard provides guidelines specific to radiation safety in the design, performance, and operation of systems used to screen persons for security purposes. It covers dose to subject, interlocks, operational procedures, information to provide to subjects, training for operators, etc.[20]

The "technical performance" measurement standards listed in Table 1 provide measurement know-how and tools with which to discriminate between competing products, ensure their safe use, gauge their appropriateness for a given task, and assess the performance of x-ray scanning equipment over time. They cover all x-ray modalities: transmission, backscatter, and computed tomography (CT).[21,18] The venues covered are reviewed below:

19. Larry Hudson, Fred Bateman, Paul Bergstrom, Frank Cerra, Jack Glover, Ronaldo Minniti, Stephen Seltzer, and Ronald Tosh "Measurements and Standards for Bulk-Explosives Detection**,"** (accepted for publication by *Applied Radiation and Isotopes, 2012, published online at* http://dx.doi.org/10.1016/j.apradiso.2011.11.029).

20. Ibid.

21. Transmission technology works on the same principle as the familiar medical x-ray device as checkpoint baggage is feed through the familiar conveyor belt set up as passengers proceed to their airport departure gates. Radiation from a source passes through the "carry-on" luggage to form an image that is inspected by security personnel. The complementary and increasingly familiar body scanning function is performed using

To support the screening of carry-on baggage in airports, DHS and NIST worked with industry to develop Institute of Electrical and Electronics Engineers, Inc. *IEEE/ANSI N42.44, American National Standard for the Performance of Checkpoint Cabinet X-Ray Imaging Security Systems*. This standard uses the method of ASTM F792-08: Standard Practice for Evaluating the Imaging Performance of Security X-Ray Systems and establishes minimum performance requirements for resolution, useful penetration, and materials discrimination.[22]

To address the safety and effectiveness of AIT systems, the development of two related standards was facilitated by NIST.[23] The recently completed results of that effort — *IEEE/ANSI N42.47-2010: American National Standard for Measuring the Imaging Performance of X-Ray and Gamma-Ray Systems for Security Screening of Humans* — provides standard methods for measuring and reporting imaging quality characteristics and establishes minimally acceptable performance requirements for security-screening systems used to inspect people who are not inside vehicles, containers, or enclosures. The analogous international standard is currently under development with the designation *IEC 62709-CD Radiation Protection Instrumentation - X-Ray Systems for the Screening of Persons for Security and the Carrying of Illicit Items*.[24] The U.S. is leading the working group, and NIST is a co-chair (with the U.S. inventor of AIT).

Currently, each piece of luggage undergoes inspection using the multiview CT technique that sends data to automated explosives-detection algorithms that produce and analyze a three-dimensional image of the luggage contents. *IEEE/ANSI N42.45-2011: American National Standard for Evaluating the Image Quality of X-Ray Computed Tomography (CT) Security-Screening Systems* is limited to test artifacts and test methods developed by NIST, and does not establish acceptable test results which are considered sensitive for reasons of national security. This standard is finding use in a growing number of international venues.[25]

Turning to the subject of cargo screening, scores of thousands of cargo containers arrive at the borders of the United States daily, by sea, truck, rail, and plane. A large number of x-ray and gamma-ray systems are deployed at the borders to inspect some of this traffic. These systems assist the officers of the U.S. Customs and Border Patrol (CBP) in their attempts to interdict contraband and people illegally entering the United States. With the need to deploy many additional inspection systems with more powerful capabilities, it became important that these systems be subjected to a common test method in order to consistently compare their performance. No national standard test procedures were available for such comparisons in 2007.[26] *IEEE/ANSI N42.46-2008: American National Standard for Measuring the Imaging Performance of X-Ray and Gamma-Ray Systems for Cargo and Vehicle Security Screening*, fills this gap. The analogous international standard, *IEC 62523 Ed.1: Radiation Protection Instrumentation - Cargo/Vehicle Radiographic Inspection Systems*, was published in 2010 and includes both imaging performance and radiation safety requirements.

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backscatter technology. In this modality radiation bounces off the body to detect objects hidden under clothing and requires much lower levels of radiation. CT technology provides three-dimensional information to an automated explosives-detection algorithm. This is the technology used to check the billions pieces of luggage that are checked annually in the United States for transport in the holds of commercial airliners. See Hudson, et. al., *op. cit.*, 2007.

22. Hudson, *op, cit.*, 2007.

23. Hudson, *op, cit.*, 2007. The two related standards whose development was facilitated by NIST IEEE/ANSI N42.47, “American National Standard for Measuring the Imaging Performance of X-Ray and Gamma-Ray Systems for Security Screening of Humans,” and HPS/ANSI N43.17,“Radiation Safety for Personnel Security Screening Systems Using X-Ray or Gamma Radiation.” The latter expanded the scope of N43.17-2002.

24. Ibid.

25. Hudson, *op. cit.*, 2012.

26. Hudson, *op. cit.*, 2007.

The use of ionizing radiation to perform security screening is presently a growth industry. The proliferation of security products that use ionizing radiation in unprecedented ways have exposed a gaps in the national and international standards where security screening is being applied. Current trends that are informing the development of second- and third-generation standards include *efforts to harmonize standards internationally*, the testing of automated-target recognition algorithms, designing test objects that may be scored objectively, using the digital imagery that is produced by today's (post-film) technologies, and designing standards that reward only technical improvements that contribute to task performance.

Manufacturers are the backbone of x-ray screening infrastructure. They conduct research, support the development of x-ray standards, and develop and support x-ray screening equipment utilized throughout the air transportation system. Table 2 identifies some of the companies that supply x-ray screening equipment of all types to the TSA and to air cargo transportation service providers (for use in airport sorting and cargo handling facilities) and their suppliers (freight forwarders and off-airport freight consolidators).

Table 2. Manufacturers of TSA Approved X-Ray Screening Equipment[27]

Screening Equipment Type	Screening Equipment Manufacturer
Advanced Imaging Technology	L-3
	Rapiscan
Explosive Detection Systems	Morpho Detection/General Electric
	L-3
	Reveal Imaging
(Non-CT) Transmission X-ray Devices	AS&E
	Astrophysics
	Control Screening
	Morpho Detection/General Electric
	L-3
	Rapiscan
	Smiths Detection

Economic Benefits of X-Ray Standards

There are three broad categories of potential beneficiaries of x-ray standards for bulk-explosives detection in air transportation venues:

- End users of air transportation services
- Public and private sector buyers of sophisticated x-ray screening equipment
- Manufacturers of x-ray screening equipment.

27. Table 2 is based on interviews with industry representatives and TSA's "TSA Air Cargo Screening Technology List (ACSTL) – For Passenger Aircraft," dated July 25, 2011.

End User Benefits

Conceptually, there are three kinds of benefits available to these users. It is reasonable to assume that many *end users* of more secure air transportation services would be willing to pay more than they currently pay for airline tickets. Enhanced security has value to airline passengers, and given greater security we would expect them to place a higher value on airline services. But competition among airlines drives fares toward costs, so we would not expect the increase in value to be fully reflected in higher fares. The typical customer will get value above and beyond the fare actually paid. One knowledgeable airline association representative estimated that consumers receive approximately 5 % more value than they actually pay for, given that some of the costs of enhanced security are "baked in" to the price through the imposition of "passenger security fees."[28] There were approximately 713 million airline enplanements in the U.S. in 2010.[29] If we assume that the average price of a U.S. airline ticket was price $222.00, the total direct value of air travel in the U.S. is in the neighborhood of $158 billion.[30] Five percent of that is approximately $7.9 billion in consumer surplus. If x-ray security standards contribute a fraction of a percent of the value of the consumer surplus airline travelers enjoy (arbitrarily, 0.0025), then the economic value attributable to x-ray security standards would be on the order of tens of millions of dollars (.05 x $7.9B x 0.0025 = $19.7M). Whatever the fractional contribution of x-ray security standards actually is, the total social benefits of air transportation security standards would be higher since this rough order of magnitude (ROM) estimate only considers the direct beneficiaries of increased airline travel security. The economic benefits of air transportation security also accrue to indirect beneficiaries whose lives and business are more secure because air transportation is more secure, for example, occupants of other potential terrorist targets, such as highrise buildings, nuclear power plants, and government buildings, and their families. In a statement arguing that airline passengers should not be charged the full cost of airline travel security, the executive director of the Association of Corporate Travel Executives (ACTE) made this point when she stated, "The truth is that air transportation is a national asset vital to the economy. When terrorists or other criminals target an airliner or an airport, they are not attacking an industry nor a user group – but the nation."[31]

Procurement Agent Benefits

Public and private sector buyers of sophisticated x-ray screening equipment *also benefit* from the development and promulgation of consensus security standards to the extent that the standards are used by procurement agents: i.) to reduce the "search costs" required to identifying reliable suppliers and the "transaction costs" of specifying and assessing contract performance; and ii.) to encourage suppliers of x-ray screening equipment to make the investments to effectively bid on contracts for very sophisticated applications and thereby causing downward pressure on the bid prices by other suppliers.[32] From a TSA procurement perspective, a reduction

28. The September 11 Security Fee is imposed on passengers of domestic and foreign air carriers for air transportation that originates at airports in the United States. The fee, which is collected at the time the ticket is bought, is $2.50 per enplanement and is imposed on not more than two enplanements per one-way trip. See, http://www.tsa.gov/research/fees/passenger_fee.shtm
29. "Fact Sheet – FAA Forecast Fact Sheet [1]–Fiscal Years 2011-31," February 15, 2011, http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=12440
30. The total operating revenue for all U.S. carriers at all major U.S. airports for 2010 is estimated at ~$175 billion. http://www.transtats.bts.gov/Data_Elements.aspx?Data=7
31. "ACTE Slams Obama on Airline User Fee," The Economist, March 7, 2009.
32. Past studies have shown, as a general matter, across industries, that the market entry of a third supplier of sufficient size ($\geq$ 16 % market share) has the effect of reducing industry profit margins by 13-14%. See, John Kwoka, "The effects of Market Share Distribution on Industry

of the number of design versions as a result of common requirements, common measurement language and common configuration controls leads to significant efficiencies. In addition, a few of the x-ray screening equipment manufacturers identified in Table 2, above, estimated that competitive pressures reduced the prices buyers would otherwise pay by 20 percent. Based on the figures presented above (in the section entitled, "U.S. Airport and Air Cargo Screening Infrastructure") there are thousands of x-ray screening machines of all types in the U.S. inventory (TSA plus those located in air cargo transportation-related facilities) with a replacement value on the order of over a billion dollars.[33] Again, if x-ray security standards contributed a small fraction to public and private procurement agents' ability to assess the comparative value of competing x-ray screening equipment vendors on an "apples to apples" basis, and induced the entry of competing firms, the economic value of that contribution would be estimated, conservatively, in the hundreds of millions of dollars. ((1.2 x $1.8B - $1.8B) = $360M).

Equipment Manufacturer Benefits

Finally, x-ray security standards reduce the development, testing, and compliance cost of manufacturing sophisticated x-ray screening equipment. A few representatives of the companies identified in Table 2, above, estimated that, on average, the development, testing, and compliance costs of sophisticated x-ray screening machines would be 40 % more costly in the absence of consensus standards. If the average unit acquisition cost of a sophisticated x-ray screening device is on the order of $300,000, and there are 6000 in the public and private inventory, a rough-order-of-magnitude estimate of cost savings to manufacturers due to the availability of consensus x-ray standards would be measured in the hundreds of millions of dollars(($300K x 1.4 - $300K) 6000 units = $720M).

Summary of Economic Benefits

Summing these kinds of economic benefits would likely entail some double counting. As summarized in Table 3, suffice it to say that a conservative, rough-order-of-magnitude (ROM) estimate of the economic benefits associated with x-ray security standards are significant, probably in the realm of hundreds of millions of dollars.[34]

Performance," *Review of Economics and Statistics, Volume 61, February* 1979, pp. 101-109;Willard Mueller and Douglas Greer, "The Effect of Market Share on Industry Performance Reexamined," *Review of Economics and Statistics,* Volume 66, May 1984, pp. 353-358;John Kwoka, "The effects of Market Share Distribution on Industry Performance: Reply," *Review of Economics and Statistics*, Volume 66, May 1984, pp. 358-361. For more general theoretical and empirical evidence that "entry" reduces prices, see F.M. Scherer and David Ross, *Industrial Market Structure and Economic Performance,* Houghton Mifflin Company, 1990.

33. Based on figures from the Transportation Security Administration, Congressional Justifications for Aviation Security, FY2008 and FY2009, the Congressional Research Service estimate the per unit acquisition cost of; non-CT advanced technology x-ray (AT) machines at ~$200,000.00; advanced identification technology (AIT) machines at ~$260,000.00; and explosive detection systems (EDS) machines at ~$500,000.00. See Elias, *op. cit.,* 2009. Based on figures from various sources, we believe that 6000 is a conservative estimate of the number of x-ray screening machines in the public and private U.S. inventory in FY2010: 2000 AT machines, 3297 EDS machines, and 500 AIT machines. If these estimates are close to accurate, the public and private inventory of x-ray screening machines could be ~$2 billion.

34. A more careful and time-consuming analysis of the quantitative impact of the suite of standards considered here would separate out the contributions of value added to each layer of the industry value added chain, estimate the benefits as well as the costs of developing these standards, and more formally survey all the significant users and producers. This case study was intended to present a *qualitative* description of the benefits of these standards and to suggest the kinds and magnitudes of the benefits they generate. Many *quantitative* impact assessments have been conducted by NIST. See, http://www.nist.gov/director/planning/studies.cfm.

Table 3. Economic Benefits of X-Ray Security Standards

Beneficiaries	ROM Benefits ($)
Air Transportation Services Users	tens of millions
Procurement Agencies	hundreds of millions
Equipment Manufacturers	hundreds of millions
Conservative Summary Estimate	hundreds of millions

Air transportation security is, by its nature, and international issue. There has been, and likely will continue to be, greater U.S.-EU collaboration on air transportation security standards.[35] The greater the international collaboration on consensus standards development the broader and greater the economic benefits will be. The contributions that consensus security standards make to air transportation service users, in the form of a willingness to pay that exceeds the market price ("consumer surplus"), the more extensive the market and the greater the number of international competitors, the greater the economic value to air transportation service users (in the form of "consumer surplus").

By the same token, the benefits that accrue to public and private x-ray equipment procurement agents in the U.S. are multiplied when other nations' suppliers compete for that business. Furthermore, the broader use of these standards by other nations' procurement agents decreases their procurement process costs as well as the unit costs of equipment via new entry into their national markets.

Finally, to the extent that consensus standards reduce the costs and risks of hardware and software development, U.S. and international companies are better able to profitably bring their innovative product solutions to new markets and contribute to a more secure international air transportation system. As the case of consensus x-ray equipment standards indicates, the "virtuous circle" development process — that begins with the formulation of customer requirements and proceeds dialectically via the mutual interchange of what is desirable and feasible on the supply side, to broad consensus among users and manufacturers, to test and evaluation protocols and test objects, and finally to customer adoption, testing and feedback — is mutually beneficial to all. Greater international collaboration would broaden these benefits.

35. For evidence of the push for greater U.S.-EU security standards collaboration, see, *The Benefits of U.S.-European Security Standardization*, NIST, March, 2012.