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The Case for Technical Performance Standards for Radiation Inspection Systems

Reference

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ABSTRACT

Technical performance standards operate within the homeland security enterprise to save significant time and money while increasing public safety. This is illustrated in this white paper through the lens of the standards infrastructure that is being developed to ensure the imaging performance and radiation safety of security screening systems in the United States that use active radiation probes to detect explosives and other contraband. The products of this effort include standard test objects, test methods, objective scoring algorithms, minimum performance requirements, technical guidance documents, and dosimetry protocols supported by National Institute of Standards and Technology (NIST) measurement science and computational modeling. This project responds to government requirements for 100 % screening of transnational cargo and airline passengers and baggage while also establishing the means to harmonize national standards across disparate agencies and with international norms. This report will show how standards gaps are identified and anticipated and outline the standards development process, especially highlighting issues unique to technical performance standardization. Specific use cases are offered that document the impact of measurement standards when applied across the life cycle of radiation inspection systems in ways that complement and inform threat-based and operational testing and evaluation (T&E). Finally, a list of specific benefits to both public- and private-sector actors is given that, based upon experience to date, demonstrates the manifold and leveraged returns from applying technical performance standards to security screening.

Keywords

technical performance standards, security screening systems, X rays, homeland security, radiation inspection

Introduction

Since 2001, the Radiation Physics Division at the National Institute of Standards and Technology (NIST) has included homeland security applications within their standards development and research portfolio. The first was a standard protocol for industrial-scale ionizing radiation used to sanitize letter and parcel mail that had potentially been maliciously contaminated with anthrax spores; this was a part of the executive branch's response to what the U.S. Federal Bureau of Investigation called the Amerithrax Case. This

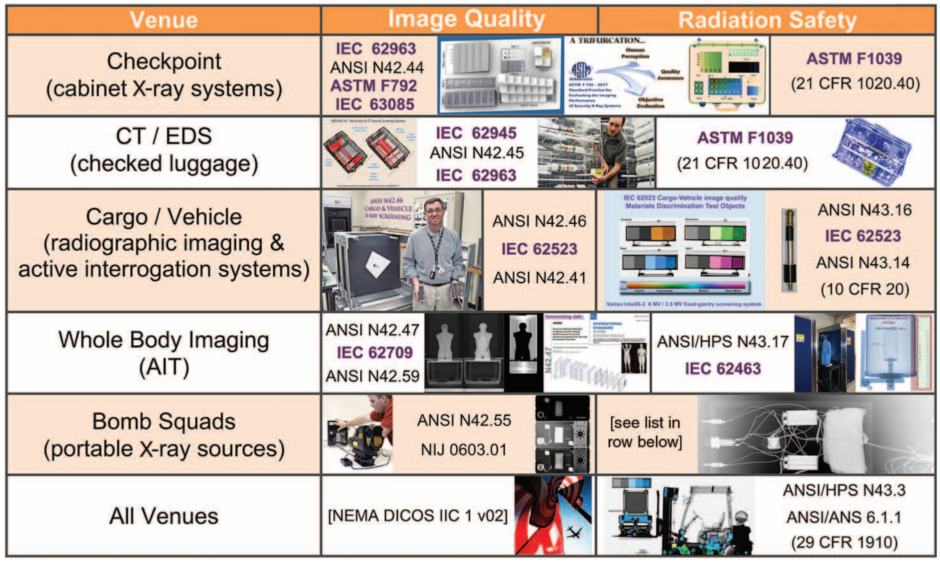


FIG. 1

Current portfolio of American national (black font) and international (bold color font) technical performance standards for radiation inspection systems. IEC 62963 [14], ANSI N42.44 [15], ASTM F792 [4], IEC 63085 [16], ASTM F1039 [17], 21 CFR 1020.40 [18], IEC 62945 [8], ANSI N42.45 [6], ANSI N42.46 [19], IEC 62523 [20], ANSI N42.41 [21], ANSI N43.16 [22], ANSI N43.14 [23], 10 CFR 20 [24], ANSI N42.47 [25], IEC 62709 [26], ANSI N42.59 [5], ANSI/HPS N43.17 [27], IEC 62463 [28], ANSI N42.55 [29], NIJ 0603.01 [30], NEMA DICOS IIC 1 v02 [31], ANSI/HPS N43.3 [32], ANSI/ANS 6.1.1 [33], 29 CFR 1910 [34].

standard tuned the maximum and minimum doses to the product while ensuring the absorbed dose was traceable to national dosimetry standards at NIST. Soon thereafter, separate groups within the Division initiated standards development programs for (1) passive radiation and nuclear detector standards and validation and (2) standards for security screening systems that use active radiation probes to detect threats. The national and international documentary standards produced by this latter effort are the subject of this report, with the goal of elucidating the special roles and benefits that such technical performance standards can and do play in the U.S. homeland security enterprise.

Overview

The lessons learned that are the subject of this report are derived in the context of facilitating the development of a portfolio of standards for security screening systems that actively use radiation as a probe for threats. In this context, the primary threat targets are bulk explosives and special nuclear material. Due to its ease of assembly and leveraged disruptive effect, the improvised explosive device has been the method of choice of terror actors to date. In recent years, explosives detection systems have been procured and applied around the world at an unprecedented level; for example, global X-ray security-screening industry revenues (including systems sales and aftersales service and upgrades) is forecasted to grow from $1.6 billion (2013) to $2.6 billion by 2020 [1]. While the most obvious use of performance standards for testing and evaluation (T&E) is to guide fiscally responsible procurement of these investments, as discussed below, measurement standards can play a wide variety of valuable roles both before and after the point of sale. The test methods currently a part of this ongoing project are tabulated in **Fig. 1** and include both national and international standards development efforts.

Discussion

As the U.S. Department of Homeland Security (DHS) was assembled, the need for national standards that could be applied across the homeland security enterprise became increasingly apparent. In a world of facile exchange of goods and people across borders, harmonization of international standards also became a priority. National and international forums and workshops helped to identify standards gaps, and lists were prioritized and pursued by subject matter experts through various standards development organizations (SDOs). In the area of explosives detection, NIST, under the direction of the DHS Office of Standards, pursued standards development and research for both trace and bulk detection technologies. For the bulk detection standards summarized in **Fig. 1** for all venues of screening, standards gaps were filled pertaining to image quality and, for the case of systems employing ionizing radiation, radiation safety. As screening technologies, reference data, and threat scenarios continue to evolve, the task often continues in the form of revisions to the core set of standards tabulated. Each of these standards are "measurement" standards of aspects of technical performance (for example, image quality or radiation exposure levels). In the following, it is argued that this category of standard complements the estimation of threat detection and operational performance and that, for a variety of reasons put forward below, both categories of standards should play a role in the T&E of security screening systems.

In America, the model is to use consensus standards over government-specific standards in federal regulation and procurement whenever possible [2]. These are produced with multistakeholder engagement, with both public and private actors motivated in part by self-interest. Whereas procedural details of the voluntary-consensus process differ by SDO (e.g., the American Society for Testing and Materials [ASTM], the Institute of Electrical and Electronics Engineers, and the International Electrotechnical Commission [IEC]), each generally includes (1) openness to all interested parties or stakeholders; (2) balance: no single interest dominates decision making; (3) consensus, in the sense of general agreement, not necessarily unanimity; and (4) due process, i.e., there are transparent procedures for resolving conflict, there is public review, all negative comments are addressed, and there is a defined appeals process.

To highlight issues specific to technical performance standards development, the following discussion will use image quality measurement standards as an example. Success in producing such documentary standards have been achieved by following these steps:

1. The process begins with the formation of a balanced working group of stakeholders. Here, key project stakeholders include federal and international government and industries participating through SDOs. Image quality standards development requires a confluence of subject matter expertise in at least four technical areas: operational knowledge of the technology under consideration (how it is used and how it works to form images), the physics of radiation interactions with both proposed test objects and the operational subjects and threats targeted by a given screening system, image-quality measurement science, and, finally, experience related to standards development of the category "technical performance." The success and speed of development of these security standards when the government is the primary buyer depends upon public agency participation and endorsement as well as the participation of the relevant private-sector manufacturer community where much of the technical expertise and innovation often reside. The industrial partners are motivated in part by a desire to compete on a level playing field, with the understanding that the standard will ultimately be used to gauge their products.
2. The first order of business for a newly assembled standards working group is to define the scope of the standard. Using image quality standards as the example, the following issues must be addressed:
   (a) While there can be some overlap, the distinction between technical performance standards and T&E based upon such and the distinction of threat detection and operational performance and its associated T&E should be delineated and clarified among the members of the working group.
   (b) The scope must also specify which types of systems will be under consideration. This includes venues, technologies, and modalities (active or passive, mobile or fixed, etc.).
   (c) Shall the standard address only imaging performance or be more wholistic and include, e.g., requirements related to safety and labeling or address extreme environmental conditions?
   (d) Shall the standard apply to an image presented to a human screener or shall the image be presented to an automated threat recognition (ATR) algorithm? In some cases, both are needed, though it is perhaps desirable that they be produced as two independent documentary standards.
   (e) Relatedly, shall the image be scored subjectively by human perception or evaluated objectively by a numerical recipe? In some cases, both are needed. In venues where a human operator is part of the detection "system," human-perception standards capture the aggregate performance of the scanner, the quality of the monitor and ambient conditions, and the training of the operator. Some venues employ ATR with human inspection of the image, sometimes only after an alarm. Even in the case of objective scoring of the image passed to an ATR, a threshold detection parameter is sometimes set to give agreement with human-judged results [3].
   (f) Shall the standard include baseline or minimum performance requirements (MPRs) or shall it be a standard test method only? Pros and cons related to this decision are offered in **Appendix A**.
3. Next, the working group attempts to identify the image quality metrics that are thought to be most relevant for threat detection in the application venue under consideration. Ideally, this is informed by the relevance of particular aspects of image quality to the perceptual task at hand. As discussed elsewhere, this connection is generally acknowledged while the specifics are lacking, but they can be better clarified by parallel technical-performance and threat-detection T&E. Competing ways to measure the identified aspects of image quality are then evaluated by the working group. This includes specifying both a test object and the method in which the screened image of the test object is evaluated; both invite simplicity and innovation.
4. Prototype test objects are then fabricated and circulated among the manufacturers and testing labs. This step may need to be iterated based upon results until the working group can converge on a standard, if not ideal, way to measure each identified image quality metric.
5. Next, drafts of the documentary standard itself are produced by volunteers of the working group and are edited for clarity. Typically, each image quality test will include the following components: title, purpose, test object description, test method, and standard presentation of results. In situations in which the results are not too application dependent nor considered security sensitive, quantitative pass-fail criteria are sometimes included.
6. Given sufficient experience with the test artifact and its registration by a variety of vendors' systems, normative or informative guidance should be given related to summary statistics and what constitutes a (quantitative) meaningful change in performance.

FIG. 2 The four categories of subject-matter expertise needed to develop image quality standards ("stds" in figure) for radiation inspection systems.

7. The final draft of the standard is then submitted to the SDO for balloting; all critical comments must be addressed.

Results

Before listing the benefits derived from applying technical performance standards to security screening applications, five specific impact- or use-case examples are given. While the following examples are drawn primarily from U.S. aviation security, the economic benefits and security enhancements outlined below can be multiplied by the development, adoption, and application of technical performance standards in other venues and by other DHS agencies or governments.

CASE 1: CHECKPOINT SCREENING OF CARRY-ON ITEMS

While always invoking national consensus standards for radiation safety, the trend at the Transportation Security Administration (TSA) has recently been toward increased adoption of national voluntary consensus standards in T&E, acceptance testing, and Functional Requirements Documents to facilitate objective procurement of systems with appropriate levels of technical performance. In 2017, the widely-employed ASTM F792, *Standard Practice for Evaluating the Imaging Performance of Security X-Ray Systems* [4], was revised to offer three test objects for different purposes: to gauge the image quality of the image presented to a human screener, objective evaluation of the intrinsic digital imagery presented to an ATR algorithm, and a simple, routine, or daily quality-assurance test object. In September 2016, the TSA began evaluating the test objects specified by ASTM F792 for use with acceptance testing of X-ray checkpoint inspection systems. Both NIST and TSA are developing analysis software that is compliant with the test methods and requirements of this international standard. One input in this exercise is the collection of X-ray images of the new test objects from a variety of manufacturers' systems that were obtained at TSA facilities using prototype phantoms during the development phase of this project.

CASE 2: PERSONNEL SCREENING

In the United States, approximately 450 federalized airports currently utilize over 790 Advanced Imaging Technology (AIT) passenger-screening systems to secure aviation checkpoints. The AIT mm-wave scanner is currently the primary tool for passenger screening in the United States, with each lane maintaining a throughput of approximately 160 passengers per hour. NIST organized and has hosted a working group since 2016 to undertake the development of a new national standard, American National Standards Institute (ANSI) N42.59, *American National Standard for Measuring the Imaging Performance of Active Millimeter-Wave Systems for Security Screening of Humans* [5]. The high level of participation of all relevant public and private stakeholders reflects the need to be able to measure and report the technical performance of these systems in a standard way. At present, the working group is evaluating the results from imaging prototype test objects with the goal of defining standard test methods for scoring various aspects of mm-wave image quality. TSA and the U.S. Transportation Security Laboratory (TSL) are leading contributors of the ANSI N42.59 working group with the expectation of applying these tools to qualification and acceptance testing as well as procurement guidance.

CASE 3: COMPUTED TOMOGRAPHY SCREENING OF CHECKED LUGGAGE

X-ray computed tomography (CT) of checked baggage for bulk explosives detection has been required for primary screening in the United States since 2003. The only standard for gauging the technical imaging performance of these types of security screening systems is ANSI N42.45, *American National Standard for Evaluating the Image Quality of X-ray Computed Tomography (CT) Security-Screening Systems* [6], developed early in this project under DHS sponsorship. The TSL reports (Lee Spanier, personal communication, May 5, 2016) that the use of ANSI N42.45 saves $54,000 for each Explosives Detection System (EDS) model they qualify (millions of dollars to date), and the TSA has adopted this national standard for factory- and site-acceptance testing of certified EDS systems before and upon deployment in U.S. airports. In 2016, Battelle began offering for purchase this ANSI test article (plus dosimetry) and analysis software as well as baseline statistics to the global aviation security market. In 2017, TSA is embedding the ANSI N42.45 analysis algorithms onto each vendor's platform to obtain more immediate performance results. This permits a technical evaluation of image quality to be performed in less than a day, compared to the 105 man-days required to fully certify an EDS system for effective threat detection.

Hence, this standard measurement tool has enabled a wide range of system-lifecycle applications:

- Developmental T&E and research (manufacturer),
- Qualification and baseline testing (TSL),

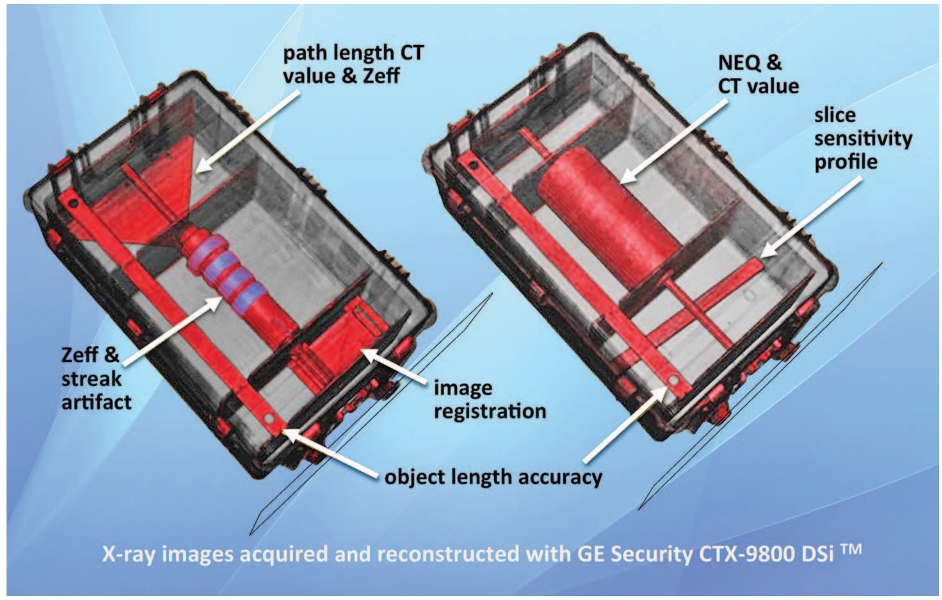


FIG. 3 A reconstructed X-ray image of the ANSI N42.45 test article for EDS systems that use computed tomography (CT) to inspect luggage in aviation security. Abbreviation: Noise Equivalent Quanta (NEQ).

- Engineering change analysis (TSL),
- Factory acceptance testing (TSA),
- Site acceptance testing (TSA), and
- Quality assurance of performance over time (TSA).

CASE 4: GLOBAL IMPACT IN SECURITY STANDARDS HARMONIZATION

Development of security standards for emerging technologies has resulted in the establishment of a new working group within the international SDO, the IEC, viz., IEC TC45 WG B17, *Security Inspection Systems Using Active Interrogation with Radiation* [7]. One impact of this is that U.S. national security standards development efforts contribute to and benefit from the analogous international security screening standards, thereby enhancing U.S. homeland security through global harmonization of standards that impact the world's commercial and transportation venues. For example, many countries around the world are now moving to CT for primary screening of checked luggage: the United Kingdom (2018), the European Union (2020), India (2018), Australia, etc. Hence it is timely that this IEC effort is ready to ballot IEC 62945, *Radiation Protection Instrumentation—Measuring the Imaging Performance of X-Ray Computed Tomography (CT) Security Screening Systems* [8], which is based upon the analogous ANSI N42.45 CT image-quality standard highlighted in Case 3 above. Previously, standards for cargo vehicles and personnel screening have been produced and adopted by the IEC as well. The working group is also currently working on standards for CT and Raman analysis of liquids at the checkpoint that could in turn be brought over as the basis for ANSI standards, were these technologies to be deployed in U.S. aviation security. Since the European Union and other state actors have adopted IEC standards, the impact has been the gradual convergence of national and international security standards at levels appropriate for the latest technologies and threat scenarios.

CASE 5: RAPID RESPONSE, QUALITY ASSURANCE, AND RESOURCE SAVINGS

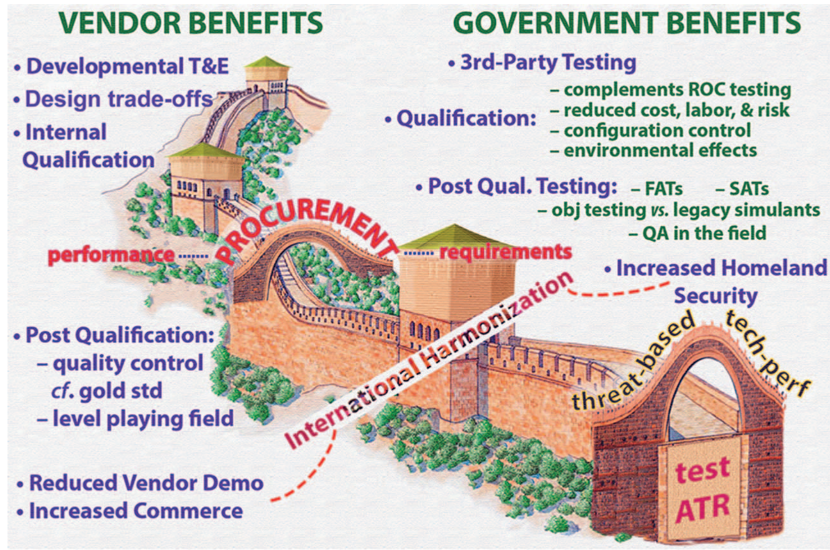
Recent DHS Office of Inspector General reports [9,10] raised concerns about the maintenance and effectiveness of transportation security equipment used to screen passengers and baggage to detect explosives and other dangerous items at the nation's 450 domestic airports. In response, the Secretary of DHS required site testing of the various classes of security screening equipment to verify continued operational performance. One of this project's deliverables to DHS has been a technical performance standard that measures the imaging performance of CT EDS (ANSI N42.45, Case 3 above). Because the Transportation Security Laboratory and the TSA had extensively applied this standard to all the vendors of fielded EDS equipment, there existed a solid technical performance baseline of a broad array of image quality metrics that could serve as a surrogate for continued operational performance (threat detection). As a result, the EDS category of hardware was readily cleared. Other categories of screening equipment that had not taken advantage of such a measurement tool throughout qualification and acceptance testing required extensive operational retesting with explosive simulants and other threats, consuming valuable taxpayer resources to confirm estimates of probabilities of detection and failure rates.

Benefits

While some of the benefits flowing from the adoption of standards for radiation inspection systems are common to most commercial products, it is interesting to discover the breadth of advantages (some unique) to applying technical performance standardization in the security screening arena. Some of these benefits attach to the vendors and some to government as the primary purchaser responsible for public safety. The following benefits have been observed to follow from applying standardized measurement of image quality. Taken together, they make the case for development and application of such standards.

1. Technical measurement standards can be used to provide points of comparison (benchmarking) during a manufacturer's developmental T&E of a new security screening system, quantifying performance improvements and reducing developmental cycle time.
2. They can provide guidance to screening system developers to arbitrate among competing manufacturing goals, informing both technical and financial design trade-offs.
3. When a customer is known to evoke particular performance standards, the seller benefits by knowing what the customer believes to be important. Such standards can be used for a manufacturer's internal qualification and system validation before submitting to third-party testing, government qualification, or the marketplace.
4. In addition to technical guidance, these first three benefits to the manufacturer also reduce the cost of production.
5. If the government requires preliminary vetting via third-party party testing, that testing could include minimum technical performance requirements tied to validated consensus standards or test methods.
6. Government qualification testing can complement traditional threat-based testing (probability of detection versus false alarm rate using actual threat scenarios) with concomitant technical-performance T&E (image quality indicators [IQIs]). This can lead to "entanglement" between these two classes of T&E; to the extent that the latter captures and measures the aspects of performance relevant to threat detection, confidence is increased that technical performance can be used postqualification as an implicit surrogate for threat detection performance, saving significant resources. This assumption is partly pragmatic; as indicated in Use Case 3 above, for EDS systems, the relative effort between these two types of T&E is >100. But at present, while it is generally accepted that better image quality leads to better threat detection, the specific connections between particular IQIs and human task performance requires further study (see benefit 18, below). Finally, it is noted that threat-based T&E is often security sensitive or secret, whereas technical performance can be measured openly with public standards, providing this benefit of convenience as well.
7. During government qualification of screening systems, use of technical performance standards can reduce the use of live-explosives testing, thereby enhancing safety of the evaluators while also reducing expenditures of time and labor.
8. Configuration control: it follows from benefit 5 above that some Engineering Change Proposals that modify a qualified system's software or hardware need not require the more burdensome suite of threat-based (re)testing if technical performance is shown to have been maintained.
9. Environmental effects testing: similarly, technical performance standards provide the measurement tools to quantify changes as a function of environmental factors.
10. Consistent use of standard testing provides assurance of performance continuity from government qualification to factory-acceptance testing (FAT) and
11. site-acceptance testing (SAT) of a given model of a screening system.
12. Such testing also permits periodic longitudinal or regression testing in the field for quality assurance. Taken with some of the previous benefits, it is clear that technical performance testing can be advantageously applied throughout the entire life cycle of a security screening system.
13. Applying technical performance measurement standards supports the postcertification trend of phasing out legacy test articles (simulants) and integrating objective and quantitative measurement tools.
14. By objectively comparing purchaser requirements against vendor model performance, technical-performance standards establish a reference point for the buyer and seller to objectively facilitate the procurement process.
15. After a model of security screening equipment is qualified by the appropriate government overseer, the vendor can use measurement standards to maintain quality control during the production of subsequent copies of the certified model.
16. Where comparisons are appropriate, quantitative results from standard test methods serve to level the playing field between vendors and their competing specification sheets. Each metric is defined and then measured in the same way. Ideally, specification sheets should report values explicitly referenced to open national or international consensus standard measurement methods.
17. Following widespread adoption of international performance standards, vendor demonstration testing is greatly reduced, saving resources and
18. facilitating the flow of transnational commerce. Other generic benefits of commercial standardization include assisting regulatory, competitive market, and policy objectives while spurring technological development, productivity, adoption, and innovation.
19. International adoption of common or harmonized performance standards enhances both homeland and global security in the transportation and commercial venues while reducing the collective T&E resource burden among cooperating governments. It is also the case that

FIG. 4
The division of benefits to manufacturers and government actors that is possible when applying technical performance standards to the homeland security enterprise. Abbreviations: Receiver Operating Characteristic (analysis) (ROC); objective (obj); Quality Assurance (QA); standard (std).



harmonization at the technical level can then lead to harmonization at higher levels of the security framework (operational, strategic, etc.).

20. The consistent use of both technical and threat-based T&E of security screening systems may establish an increasingly discerned causal bridge between various aspects of technical performance and their relative contributions to threat detection for a given venue or technology. This has been attempted using human perception studies [3,11]. This research direction has the potential to direct future design requirements and save money, whereas extra technical performance is shown not to be advantageous to task performance.
21. This connection of threat detection to task performance will increasingly apply to nonhuman performance (ATR). ATR software can be tested, compared, and quantified by using a suite of images whose technical metrics have been varied and objectively analyzed using technical performance and image quality standards, and correlations can be made that inform where technical investments should be most profitable.

Conclusions

It has been shown that the application of technical performance standards for radiation security screening systems contributes far more than simple procurement guidance to government-end users. The use cases and list of benefits to both manufacturers and purchasers enumerated herein argue that the development and adoption of such standards offer valuable measurement tools through the entire life cycle of explosives detection systems. The case for technical performance standards and the security enhancements they offer adds to the conclusions of previous studies that have estimated the significant annual economic benefits and time savings for government customers [12,13]. It is also concluded that such technical performance measurement standards do not compete with, but rather complement, the use of threat detection and operational standards used in the T&E of systems that use radiation to actively screen for threats and other contraband. Together, they are necessary components in the success of the homeland security enterprise.

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Commercial equipment identified in this paper is not intended to imply recommendation or endorsement by the U.S. government, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

Appendix A: Minimum Performance Requirements

When deciding upon the scope of effort, a standards-developing working group should consider whether it is helpful or useful to include baseline or MPRs. To some, a standard is something one either passes or fails, so quantitative requirements are assumed. But in the case of image quality standards, it is often the test object (s), test method, and method of analysis that are standardized with no mention of what quantitative scores are considered acceptable. The following arguments for and against inclusion of MPRs in an image quality standard can help frame the issues for the working group and their decisions regarding scope. Here, the discussion is on performance related to imaging; such a standard could also include system requirements (not minimum), related electromagnetic compatibility and immunity, radiation and electrical safety, environmental conditions, etc.

One argument against including MPRs is that they could be misunderstood as sufficient for all applications of a given technology or venue. Strictly speaking, this is a misapplication of the standard rather than a fault of the standard itself. Nevertheless, there can be dire financial and security consequences if security screening systems are procured (often in quantity) that are not performance-matched to the venue into which they are fielded. There is also the risk that the MPRs are chosen to be too demanding, potentially restricting commerce unnecessarily. Another consideration follows from the inexact connection between various aspects of image quality and the actual task of detecting threats or contraband. If, for example, a detection algorithm can trade off against the performance of different image quality metrics and maintain the same probability of detection, then requirements on individual metrics can be misplaced. In situations in which an operator screens the images, human perception studies are needed to weigh the relative effectiveness of various IQIs to perceptual task performance. Such human-factors research is a daunting task given the nearly unlimited threat scenarios possible. Again, these observations do not argue against MPRs per se, but they highlight the challenge of assigning an appropriate value of minimum performance to each individual IQI (not all of which are always truly independent). Such an assignment requires subject-matter expertise on the working group that understands both the range of application venues and their different performance demands (needs-driven MPRs) as well as the range of capabilities of current imaging technology (in balance with technology-informed MPRs). In some applications, even minimally acceptable performance may be considered security sensitive and should not, therefore, be included in a public consensus standard. Finally, sometimes the venues or the technical implementations of the screening systems being standardized are so disparate that the working group may decide that it is impractical to define the many subcategories and their corresponding requirements.

The argument most often put forward for including MPRs in a standard, when they are not precluded by the above considerations, is that they can provide helpful guidance to less technical users or less demanding situations. Take, for example, checkpoint screening systems. In aviation security, the performance requirement is very high, and those responsible for testing and evaluating checkpoint screening systems do not require technical guidance in the form of MPRs. But checkpoint systems are also used in schools, sporting venues, public events, courthouses, and other public buildings. Many federal, state, local, and tribal agencies do not have the resources to perform independent testing nor the technical expertise to choose which systems meet their level of screening requirements. The ability to exclude systems that do not meet nationally recognized MPRs helps to inform these resource and expertise gaps. Standards with MPRs could also be useful to the aviation security enterprise were it to require third-party testing to vet systems before the more onerous process of qualification testing. Finally, if the standards development working group decides that the inclusion of MPRs adds value to some end users and applications, their inclusion does not inhibit other users from requiring more demanding technical performance.

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