Discussion Draft

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This draft report was prepared by NIST staff at the request of the Technical Guidelines Development Committee (TGDC) to serve as a point of discussion at the Dec. 4-5 meeting of the TGDC. Prepared in conjunction with members of a TGDC subcommittee, the report is a discussion draft and does not represent a consensus view or recommendation from either NIST or the TGDC. It reflects the conclusions of NIST research staff for purposes of discussion. The TGDC is an advisory group to the Election Assistance Commission, which produces voluntary voting system guidelines and was established by the Help America Vote Act. NIST serves as a technical advisor to the TGDC.

The NIST research and the draft report's conclusions are based on interviews and discussions with election officials, voting system vendors, computer scientists, and other experts in the field, as well as a literature search and the technical expertise of its authors. It is intended to help in developing guidelines for the next generation of electronic voting machine to ensure that these systems are as reliable, accurate, and secure as possible. Issues of certification or decertification of voting systems currently in place are outside the scope of this document and of the TGDC's deliberations.

VVPR Issues and STS Recommendations for the TGDC

November, 2006

Acronyms and Terms Used in This Paper

The following acronyms and terms are used in this paper. These terms are also defined in the draft VVSG 2007 glossary, located at http://vote.nist.gov/TGDC/VVSG2007-glossary-20061011.doc.

- **Ballot of Record** – the ballot used as the official record of a voter's choices in an election
- **CCOS** - Central Count Optical Scanner
- **CRT** – Core Requirements and Testing subcommittee of the TGDC
- **CVR** - Cast Vote Record, can be the electronic or paper record of voter choices
- **DRE** – Direct Record Electronic
- **DRE-VVPAT** – A DRE with a Voter Verified Paper Audit Trail
- **EBM** – Electronic Ballot Marking device, e.g., the ES&S AutoMARK
- **EML** – Election Markup Language, standard for the structured interchange of voting-related data, e.g., electronic CVRs
- **HFP** – Human Factors and Privacy subcommittee of the TGDC
- **MaxiCode** – a public domain symbol system created and used by UPS; it resembles a barcode but uses dots arranged in a hexagonal grid instead of bars
- **MMPB** - Manually Marked Paper Ballots
- **OCR** - Optical Character Recognition
- **Op Scan** – voting systems in which a voter completes a paper ballot, either by hand or via an EBM, and then the ballot is scanned by an optical scanner
- **PCOS** - Precinct Count Optical Scanner

- **PDF417** – Portable Data File 417, a public-domain 2-dimensional barcode used in a variety of applications including ID cards and Inventory management
- **STS** - Security and Transparency Subcommittee of the TGDC
- **TGDC** - Technical Guidelines Development Committee
- **VSTL** – Voting System Testing Laboratory
- **VVPR** - Voter Verified Paper Records

1. Introduction

This paper discusses the general approach proposed for VVSG 2007 requirements for voting systems that produce Voter Verified Paper Records (VVPR). This paper provides a variety of pros and cons regarding issues such as usability of paper records by election officials in audits, issues with paper rolls and privacy, and use of barcodes. It also includes discussion for requirements for EBMs.

1.1 Purpose

The purpose of this paper is to inform the TGDC about various issues regarding use of paper records and the associated STS recommendations. The STS is proposing that the VVSG 2007 will contain requirements only for software-independent voting systems; currently, voting systems meeting the definition of software-independence produce/use voter-verified paper records. Therefore, the TGDC must make informed decisions on a variety of different issues that relate to the security, integrity, usability, and accessibility of paper records, both for voters and for election officials.

1.2 Voting Systems That Use VVPR

There are three types of voting systems that use VVPRs:

1. DRE-VVPAT voting systems, in which a paper record of the voter's CVR is produced; each electronic CVR can potentially be compared with its paper counterpart.

2. EBM, in which an EBM is used to produce a paper CVR that is then scanned by a PCOS or CCOS; the paper CVRs can be audited against the totals or records stored by the scanner.

3. MMPB in conjunction with a PCOS.

VVSG 2007 will describe these systems as *classes* of voting systems, which are in essence equivalent to *profiles* of voting systems that can be certified under the VVSG.

1.3 VVPR Usage by US States

6 of the top 10 most populous states use or soon will be using voter-verified paper records throughout (CA, NY, IL, OH, MI, and NJ); in 3 of the remaining 4 states (TX, FL, PA) it

varies from county to county (e.g., in Florida 52 of 67 counties use op scan plus an accessible device)[1].

A summary of state usage is as follows:

- 27 states mandate voter-verified paper records statewide
- 8 don't mandate them but use them statewide
- 10 use them on a county-by-county basis
- 5 states use only DREs statewide (DE, GA, LA, MD, SC)

Thus a total of 35 states use voter-verified paper records throughout. Over half of all voters in the 2006 elections used voter-verified paper records; 49% of voters alone used op scan[2].

2. VVPAT vs. VVPR Terminology and Scope

The VVSG 2005 contains a section on DRE-VVPAT that, with some exceptions, stands alone as a separate standard, however the term *VVPR* is not mentioned anywhere in VVSG 2005. One potential issue with this sole use of VVPAT terminology is that it may be confusing to legislators who wish to consider use of voting systems that produce/use VVPR, i.e., the paper audit trail produced by DRE-VVPAT is just one form of VVPR, there are others that may be more preferable to certain states and localities. Other types of voting systems do or could produce a VVPR, e.g., op scan being one example.

For VVSG 2007, the NIST has decided to include a more general section on voting systems that produce/use VVPR, and include within this section a discussion of requirements for DRE-VVPAT as well as op scan and EBM.

The DRE-VVPAT section in VVSG 2005 contains some usability/accessibility-related and mechanical reliability requirements aimed at the voter. The VVPR section in VVSG 2007 will not contain these sorts of requirements but will incorporate them via the VVSG's class structure. However, the VVPR section will contain requirements whose purpose is to make the paper records (in particular the paper rolls) more usable to election officials and thus more useful in audits.

3. Paper Record Usefulness in Audits

A number of election officials and others involved in elections have maintained that paper ballots and paper rolls (in DRE-VVPAT) greatly complicate election management and, in fact, decrease the accuracy of the election results if the paper is used as the ballot of record or in recounts. Paper has been lost or stolen; it can be switched or otherwise tampered with[3].

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[1] See http://www.house.gov/science/hearings/full06/July%2019/Wagner.pdf and http://www.verifiedvoting.org/index.php.

[2] See http://www.edssurvey.com/images/File/ve2006_nrpt.pdf.

[3] Generally speaking, this has occurred when accepted practices and procedures have not been followed. But if people fail to follow accepted procedures, then *any* voting system can become insecure. It is arguable that some state-mandated procedures required to handle and transport paperless DREs safely

Proponents of this argument often cite as an example the current implementations of DRE-VVPAT, which do have significant, but to a certain extent fixable usability issues. Somewhat as a result, paper gets blamed as being inherently difficult to handle in elections.

To a large extent, though, the usability[4] of the paper record depends on how well the voting system in question has been designed to work with a paper record or whether the paper record is an afterthought. Current examples of DRE-VVPAT are a good example: current DRE-VVPAT is basically a DRE with a printer grafted on. Current implementations of DRE-VVPATs using relatively small paper rolls with unreliable mechanisms are not as usable or accessible as they could be if designed from the ground up to use paper. Some studies assert that use of EBMs might be a more usable and accessible approach than DRE-VVPAT, for example[5], because the EBM is designed specifically to be usable, accessible, and to produce a larger, more complete and legible paper ballot.

3.1 How System Design/Configuration Affects VVPR Usefulness in Audits

One notable study of usability for election officials is the ESI report of their audit of DRE-VVPAT systems in Ohio, which pointed out many correctable problems with the use of paper records and paper rolls[6]. This study was particularly useful because it showed how a series of voting system setup decisions earlier in the election preparation resulted in difficult-to-audit paper records. Most, if not all of these problems resulted from various failures in the voting system reliability and its setup for use in the election, and were not problems inherent in the use of paper as the audit record.

Problems that resulted in this election included:

- The voting system identifiers printed on the paper record were assigned by the election and were different from actual physical serial numbers on the voting systems themselves, thus it was difficult after the election to associate paper rolls with the systems that produced them.
- The DRE-VVPATs were used at multi-precinct polling places but precinct information was not printed on the paper records, and it was difficult to determine which paper record belonged to which precinct under audit.
- If multiple paper spools were required, it appeared that the voting system identifier was printed only on the first paper spool used, and no subsequent linking information was printed on the remaining other spools.
- It appeared that the voting system was capable of being programmed to print out various sorts of reports with the records but the capability was difficult to use -- it is possible that the system could have been programmed to report the precinct with each paper record.
- A number of the paper records jammed or "accordioned" in the printer compartment, thereby rendering the paper trail unusable.

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are even *more* burdensome than the procedures for handling and transporting paper. See, for example, California's procedures, http://accurate-voting.org/wp-content/uploads/2006/11/DESI_AV-TSX_AVPM_Procedures_(2006-05_FINAL).pdf, especially pp. 65-67 and p. 70, and Colorado's court-ordered procedures, http://www.votingintegrity.org/pdf/co_secure-evoting.pdf, especially Sections 1, 5, 6, 8, 9, and 10.

[4] *Usability* gets used here to describe the usefulness of the paper records in audits.
[5] See http://vote.nist.gov/SaltmanRpt20060815.pdf and http://www.wired.com/news/politics/evote/0,71957-0.html?tw=wn_politics_evote_8.

[6] See http://bocc.cuyahogacounty.us/GSC/pdf/esi_cuyahoga_final.pdf.

- The vendor provided no tools to assist in auditing the papers spools and provided insufficient documentation for conducting an audit.

The Cuyahoga audit shows that certain design or configuration choices can make the paper (and electronic) records more or less usable. Some of these configuration mistakes, such as dynamically assigning system identifiers, aren't immediately obvious as affecting the usability of the paper records. However, when (easily-correctable) problems such as these occur, the result is that the DRE-VVPAT (or any other voting system using VVPRs) becomes inauditable and in that regard no better than a DRE.

3.2 Resultant Recommendations for DRE-VVPAT and VVPR Voting Systems

It is first necessary to discuss what sorts of equipment usage and audit scenarios the VVPR requirements in VVSG 2007 are to address. The requirements should anticipate that VVPR voting systems will be used in a variety of different environments, including precinct-less voting centers, and will be used for early voting and provisional voting as well as on Election Day. Potentially, then, the same DRE-VVPAT system could be used on the same day for regular or provisional voting and for multiple elections in multiple precincts. Consequently, the requirements for information on the records should anticipate that an auditor must be able to identify from each record the following information:

- A permanent identifier of the voting system[7] (corresponding to the equipment serial number and the same from election to election)
- The election ID
- The ballot style
- The type of voting (early, etc.)
- The precinct and polling place
- An optional unique identifier that links each paper record to its corresponding electronic record

Additionally, if a paper roll is used, the voting system should keep track of which roll is in use and print a sequence number in a header. It should also make a final printout of the total number of paper/electronic records it has stored at the end of each roll. The vendor must include mechanical tools or other devices needed for handling spooled paper records; failure to do so would be egregious.

The voting system should *never* be able to record an electronic record and at the same time fail in properly creating or storing the paper record. Thus, paper jams or running out of ink or paper, or other situations should never go undetected by the voting system. Paper jams and other similarly easily-corrected complications of printing should in practical usage almost never occur; if cash registers, gasoline pumps, and lottery ticket printers can virtually eliminate paper jams, so should they be eliminated in voting systems.

The usability of the voting system for configuring reports and documenting audits is especially important. The vendor needs to thoroughly document how to set up the system so that it provides the requisite information for conducting audits and also include detailed instructions showing how the voting system is to be audited using the paper records.

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[7] The consequences of having a permanent identifier of the voting system may extend to associating public and private digital key pairs with each voting system, and having the identifier linked cryptographically to the system identifier. This is discussed more in the Security and Audit Architecture paper prepared for the December 4/5 meeting of the TGDC, located at http://vote.nist.gov/SecurityAndAuditArchitectureSummary.pdf.

Lastly, whether the voter-verified paper record is to be used as the ballot of record in an election is outside the TGDC's scope. However, as required by states, the paper records should support use as the ballot of record in recounts.

4. Use of Paper Rolls in DRE-VVPAT Systems

At present, most if not all DRE-VVPAT systems print and store the voter verified paper records on a continuous paper roll. Paper rolls have received a significant amount of criticism for a variety of reasons, however some of the criticisms, e.g., difficulty of handling spools of paper in audits, have less to do with the paper rolls themselves and more with the lack of mechanical aids to make handling easier.

The VVSG 2005 DRE-VVPAT requirements permit use of paper rolls, with several restrictions:

- There must be a privacy container that is handled essentially as a ballot box.
- No records can be kept of who used the voting system or the order in which the voters used the voting system[8].

4.1 Pros and Cons of Using Paper Rolls

The **cons** or drawbacks associated with continuous paper rolls include the following:

- They preserve the order in which voters have used the voting system, which potentially poses risks to voter anonymity.
- Their current small size limits the amount of information that can be displayed at one time to the voter, but this could be improved, e.g., scrolling or using wider paper.
- They are difficult to handle in audits if unassisted by any mechanical aids.

The **pros** or benefits associated with continuous paper rolls include the following:

- All paper records are contained on one or more spools and thus are easier to transport and handle than individual sheets of paper.
- The thermal printers are relatively simple and can be made to be very reliable.
- Existing DRE-VVPAT systems can be certified to the VVSG 2007 without needing hardware changes.

The advantages to using paper rolls include, significantly, that existing DRE-VVPAT systems could still meet the DRE-VVPAT requirements in VVSG 2007.

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[8] This is a requirement for a voting system procedure, which is beyond the scope of VVSG 2007. It seems intuitively obvious that no records of the order in which voters used a system should be kept, but a record maintained by election officials of how many voters used a particular system is necessary information for auditing purposes.

4.2 Paper Roll Recommendations for VVSG 2007

The STS proposes to continue to permit the use of paper rolls for VVSG 2007, however there would be additional requirements as to their format and usefulness in audits. The primary justification for continuing to permit their use is that this permits existing DRE-VVPAT systems to still be certifiable under VVSG 2007 and it therefore gives election officials more choice in voting systems.

Some of the drawbacks listed here for paper rolls can be improved upon or mitigated with relatively simple measures. While nothing can be done about the sequential order in which records are stored on the rolls, privacy enclosures can be required to detect any opening of the spools at the polling site, where any potential identification of voters from the ordering of the records is most likely to occur. Mechanical aids can be required to make the records easier to handle by auditors. If multiple paper rolls are used, information can be printed to identify the sequence of the rolls.

But, paper rolls are not in general a good approach. Future voting systems should not use a technology approach that requires an inherent violation of voter privacy. The VVSG 2007 should include a statement to the effect that continuous rolls of paper should not be used. The "should" requirement doesn't mandate this, but it telegraphs a signal that future voting systems should move away from this technology and implement an approach that does not violate voter privacy.

5. Barcodes and Encoded Information on Paper Records

Presently, DRE-VVPAT systems offer the option of including a barcode that contains ballot choice information with each paper record. At least one EBM system contains a similar barcode. The barcodes can be scanned by commercial off-the-shelf barcode scanners and the resultant information can be saved in an electronic format at a far faster rate than if accomplished through manual means. Perhaps the most significant drawback to use of barcodes is that the voter cannot see what information is contained in the barcode, thus the barcode is a significant vector for attack on the voting system.

The VVSG 2005 DRE-VVPAT requirements permit use of barcodes: "If [*sic*] barcode is used, the voting equipment shall be able to print a barcode with each paper record that contains the human-readable contents of the paper record." The barcode shall use an industry standard format, e.g., MaxiCode or PDF417, and shall be able to be read using readily available commercial technology, and shall not contain any information other than the paper record's human-readable content, error correcting codes, and digital signature information.

5.1 Pros and Cons of Using Barcodes on Paper Records

The **pros** or benefits associated with using barcodes and any otherwise encoded information on paper records include the following:

- As mentioned previously, scanning the barcodes and saving them in an electronic format, for the purposes of a recount only, can be done significantly faster and potentially more accurately than through manual means (provided proper auditing of whether the barcodes match the VVPR records has occurred).

- The barcodes occupy relatively small amounts of space on the paper record yet can encode a relatively large amount of information.
- Information such as unique identifiers that link the paper records to their electronic counterparts can be hidden in the barcode so as to prevent voters from identifying their paper records.
- Some experts have concluded that the barcode can be scanned faster and more reliably than using OCR technology.

For recounts, there are some benefits to including the barcode because it can be scanned and saved significantly faster and arguably more accurately than through manual means. However, the real benefit is that the barcodes should match the voter-verified human-readable paper records. Thus, recounts using barcodes can be accomplished *if and only if* the barcodes have been determined via an audit that they do indeed match the paper records. In some sense, the barcode is an attractive nuisance because its inclusion could have the negative effect of encouraging officials to use solely the barcode in recounts or audits. Indeed, some election officials have stated to NIST that in audits, they scan the barcodes and ignore the human readable content. It cannot be overstated that the barcode is not a voter-verifiable paper record and its use by itself in audits or recounts *completely negates* the whole purpose of voter-verified paper records and opens the door to serious security vulnerabilities.

The Open Voting Consortium[9] has produced a voting system prototype that uses barcodes. OVC agrees that the barcodes must be audited before they can be used in audits. OVC's reasons for including them include that barcodes are easier to handle and less prone to scanning error than with OCR, and that the barcodes lend some integrity to the human readable part of a paper record if the human readable part is somehow damaged or written upon or forged. If the barcodes include precinct or machine identification information, using a barcode scanner could help in sorting the ballots into separate piles (for flat-cut sheets of paper). There is no argument that the barcodes can be useful.

The **cons** or drawbacks associated with using barcodes on paper records include the following:

- The voter cannot read the barcode and thus is forced to approve a paper record he or she cannot fully read.
- Erroneous information can be placed in the barcode without the voter's knowledge.
- The barcode is a third record of the voter's choices and the complications of keeping all records in correspondence and ensuring their accuracy is thus more complicated than with just an electronic record and a human readable paper counterpart.
- It is attractive to use only the barcode in audits of the electronic records. Again, this defeats the whole purpose of using voter-verified paper records and opens the door to serious security vulnerabilities.

5.2 Barcode and Encoded Information Recommendations for VVSG 2007

The STS proposes that VVSG 2007 permit information on the paper record to be encoded for the purposes of facilitating accurate machine scanning of the records. The STS also proposes that the method for encoding any information be fully public and supported by off-the-shelf products. The software shall be tested by VSTLs as part of the voting system certification.

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[9] See http://www.openvotingconsortium.org/our_solution.

But in general, it is not advisable to place information on a ballot that a voter cannot read; it intuitively violates the principle of voter-verification. In addition, it is a significant attack vector. The VVSG 2007 should include a statement to the effect that encoded information should not be used if possible, and alternatives such as more legible and thus more easily scanned paper ballots should be used instead.

6. New Requirements for EBMs and Optical Scanners

Use of EBMs holds great promise for usability, accessibility, and security. It may well be that the combination of an EBM and an optical scanner is a simpler approach than VVPAT. Some new requirements in VVSG 2007 are envisioned for EBM's and optical scanners to facilitate auditing and interoperability. Research for these requirements is not complete, but will be accomplished in time for VVSG 2007. These are summarized as follows (this discussion is preliminary and does not represent any NIST or any TGDC recommendations):

6.1 Optical Scanners to Store a Record per Ballot Scanned

If the optical scanner is capable of storing a record per ballot scanned, it should do so. Potentially, this could include a scanned image of the ballot as well. Accordingly, it should be able to export the records in a common format (e.g., EML) and create appropriate reports. The CRT is investigating this capability.

6.2 EBMs to Digitally Sign Each Paper Record

An EBM could digitally sign each paper record it produces and stamp this signature on the paper. This would prevent the addition or substitution of ballots. Research for requirements in this area is not complete, but it appears as if such digital signatures on paper records could increase their security and usefulness in audits.

6.3 Interoperability between EBM and Optical Scanner

The VVSG 2007 should include requirements to eliminate barriers to development and deployment of EBMs. One barrier is interoperability between EBMs of one vendor and optical scanners of another vendor, thus EBMs should produce paper records that can be scanned by different brands of optical scanners and vice versa. This would further security and give election officials more choice by permitting use of equipment from different vendors.

The issue of interoperability needs more discussion by the TGDC. A major barrier to interoperability is that if a manufacturer of EBMs wants to sell their EBM for use with some other vendor's scanners, then they must effectively beg permission from the other vendor. The other vendor has, in effect, a veto over the concept of a hybrid system that combines the first vendor's EBM with the other vendor's scanner. This "vendor veto" appears to be a major barrier to deployment of EBMs, and giving each vendor this kind of "veto" power is harmful and contrary to the public interest.

One basis for the "veto" is the standard's requirement to certify voting equipment as a whole system: an EBM vendor would have to submit documentation and working units that include an EBM and another vendor's scanner, for example. While there are good reasons for certifying whole systems, perhaps a vendor could make their op scan systems available to test labs upon demand for use in interoperability testing with an EBM submitted by another vendor. More discussion is needed here with EBM vendors.

7. Conclusions and Recommendations

The primary issues and associated STS recommendations are as follows:

1. **Use of paper rolls:** STS recommends retaining requirements from VVSG 2005 that permit the use of paper rolls. Modifications are recommended to increase security of housings for paper spools. STS recommends including a statement to the effect that paper rolls should not be used in new voting systems.

2. **Use of barcodes:** STS recommends retaining requirements from VVSG 2005 that permit the use of barcodes, with certain restrictions. STS recommends including a statement to the effect that barcodes should be avoided if at all possible.

3. **Tools provided by vendor to handle/scan paper rolls:** STS recommends that vendors provide mechanical aids for spooling paper rolls to facilitate manual audits and scanning of barcodes. Software would be provided that would use an off-the-shelf barcode scanner to read the barcodes and store them electronically; the software would be inspected by testing laboratories and require certification.

4. **Usability and Accessibility issues:** STS recommends that usability and accessibility issues for voters and for election officials for DRE-VVPAT and for other systems that use paper records be studied further. HFP and STS should collaborate and approach recommendations together.

5. **Use of EBMs:** STS recommends that NIST research interoperability and "vendor veto" issues with EBM vendors so as to identify barriers to EBM development and deployment. STS recommends that other requirements for improving the utility of EBMs be investigated.