Machine-Marked Printed Vote Records

Recommended Principles and Guidelines

OSET INSTITUTE

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About the OSET Institute

The Open Source Election Technology ("OSET") Institute is a 501(c)(3) tax-exempt nonpartisan, nonprofit election technology research corporation chartered with research, development, and education in election technology innovation.

The Institute's flagship effort, the TrustTheVote™ Project is developing **Elect**OS™, a next generation higher integrity, lower cost, easier to use election administration and voting technology framework freely available for any election jurisdiction to adopt, and have professionally adapted and deployed. ElectOS and all open source election technology is being designed and engineered per the requirements and specifications of election officials, administrators, and operators through a Request For Comment (RFC) process.

As part of our research, development and education mission, from time to time, the Institute produces Briefings and other content to inform stakeholders, supporters, and the public about issues of election technology innovation and integrity.

Threats to our election administration technology infrastructure are inherently threats to our democracy

Acknowledgements

The OSET Institute and the principal author acknowledge and thank the Center for Civic Design, the National Institute of Standards and Technology (NIST), the Verified Voting Foundation and Steven J. Ricchetti of the Penn-Biden Center for Diplomacy and Global Engagement for inspiration in the conception and development of this paper, the structure of content herein which is similar in some respects to the Center for Civic Design's *Principles and Guidelines for Remote Ballot Marking Systems*.

About the Author

Edward Perez is the *Global Director of Technology Development* for the OSET Institute. He focuses on election technology data standards, certification, audit, user-centered design and security-centric engineering practices. Edward also contributes to election law research, technology policy research, and government relations. He also is a principal liaison to the TrustTheVote Project elections officials staekholder community. Mr. Perez earned his Master's degree from the University of California, Berkeley and his undergraduate degree from Georgetown University.

Prior to joining the OSET Institute, Edward directed product management for Hart InterCivic, one of the three major voting systems vendors in the U.S. Mr. Perez is a voting systems and election administration technology expert, with 15 years direct experience at Hart InterCivic where he applied his deep election administration knowledge to drive product development, voting technology design, federal and state certification, systems implementation, field service and support, and voter education initiatives.

Mr. Perez brings practical experience in all marketplace and technical requirements that structure the development and delivery of election technology to end-users in the United States, including voters, election staff, and polling place officials. Edward speaks regularly on these topics including most recently, the National Academies of Sciences, Engineering, and Medicine (NASEM), Committee on the Future of Voting, December 2017; National Conference of State Legislatures (NCSL), Future of Elections: Technology Policy and Funding Conference, June 2017. Mr. Perez is also co-inventor of U.S. patent US8985435B2 in the domain of voting technology assigned to Hart InterCivic, Inc.

OSET Institute Supporter Acknowledgement

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Preface

The OSET Institute was founded with a mission to increase confidence in elections and their outcomes in order to preserve democracy everywhere. Our work naturally flows from that: innovation in election technology to increase integrity, lower cost, improve usability, and ultimately improve participation. There are many technologies necessary to innovate Election Infrastructure.

Election Infrastructure, being one sector of Critical Infrastructure means that research the Institute performs for Election Infrastructure innovation can have application to Critical Infrastructure in general. Occasionally, the OSET Institute presents research and policy thinking about technology that has application across all sectors of Critical Infrastructure, and without regard to election administration, specifically.

More often, however, the Institute prepares and presents research and policy thinking, including recommended principles and practices—from design to engineering through to development and implementation. We do so with a user-centered design approach with a security-centric engineering mandate.

The Institute's fiscally sponsored TrustTheVote™ Project is working on a public technology framework called ElectOS™. This framework is based on several principles and best practices and is designed to be a generational platform capable of supporting innovations in all aspects of election administration and voting. One fundamental principle provided by stakeholders is the necessity of a paper ballot of record. It has been said the ballot is the currency of representative democracy. Therefore, ElectOS fully embraces the principle of a paper ballot of record.

The 2018 midterm election confirmed the importance of a paper ballot of record and the need for post-election audits. Accordingly, the use of paper in elections is all the buzz, and an emerging solution of choice is the use of "hybrid" ballot marking devices that produce "summary" paper vote records.

Without wandering into the activist and political rage over hand-marked vs. machine-marked ballots and the associated issues, this Briefing examines an important set of principles and guidelines if a machine-marked paper vote record is the system of choice for casting a ballot. We believe there is value to an accessible ballot marking device, not only for those who require the device as a condition precedent to their enfranchisement, but it can help several issues such as under-voting, over-voting, and completing the down-ballot. However, the Institute has a mandate in this solution: *a paper ballot of record*. And to that end at this time, we're *not* in favor of solutions that generate an encoding mechanism (e.g., QR code) for counting ballots.

Our position is that a Printed Vote Record must be an auditable, durable paper record of a voter's choices produced by a digital marking device. To achieve that, there are principles and guidelines for the design and implementation of this type of device that can avoid the risk and likelihood that some solutions being raced to market may adversely impact verifiability, usability, accessibility, privacy, cost-effectiveness, and other important values in voting and election administration. **Edward Perez**, *Global Director of Technology Development* for the OSET Institute, tackles those issues in this timely Briefing.

Executive Summary

Following the U.S. Intelligence Community's conclusion that Russia attempted to interfere with the 2016 Presidential Election, ensuring the integrity of elections in the U.S. is appropriately a topic of great focus. In this context, particular attention has been paid to the importance of auditable "paper trails" for voting devices.

One type of paper trail solution that is becoming increasingly popular among some election officials is the use of "hybrid" ballot marking devices that produce "summary" paper vote records. These types of paper vote records differ from traditional ballots insofar as they are machine-marked, and they capture contest titles and voter choices (only) in human-readable text format. Particularly for jurisdictions that require "touchscreen voting" or "machine-style voting," and resist the use of hand-marked ballots as a perceived "step backward," hybrid devices that produce summary paper records are a source of growing interest. Design considerations for this alternative type of paper record are the subject of this paper.

A Printed Vote Record (PVR) is defined as an auditable, durable paper record of voter choice selections produced by an electronic marking device. Currently, several commercial voting system manufacturers have developed and attained certification of diverse implementations of PVRs. PVRs represent an emerging technology in need of uniform design principles, best practices, and additional research. The relatively fast pace by which hybrid devices with PVRs are being pushed out to the marketplace raises the risk and likelihood that some designs may adversely impact verifiability, usability, accessibility, privacy, cost-effectiveness, and other important values in voting and election administration.

This Briefing summarizes the current state of the commercial offerings for these products; identifies concerns and design challenges reflected in current implementations; presents principles and guidelines for future PVR development; identifies areas in need of additional research; and concludes with some high-level considerations about differences between traditional hand-marked ballots and machine-marked PVRs.

Ten Design Principles

Based on current technology trends, and with a particular emphasis on enhancing the overall integrity of the voting experience, this Briefing identifies ten principles for the design and development of machine-marked Printed Vote Records (PVRs):

Principle #1: Transparent

PVRs display and tabulate voter choices in a manner that is understandable to the voter.

Principle #2: Voter-Verifiable

PVRs allow voters to directly verify the same human-readable text that the voting system uses for purposes of tabulation.

Principle #3: Secure

PVRs ensure the integrity of the vote and do not allow voter choices to be changed without detection.

Principle #4: Usable
PVRs support a voter's ability to review his/her printed choices for accuracy before the ballot is cast.

Principle #5: Accessible
PVRs are accessible to the broadest possible range of voters.

Principle #6: Tested
PVRs have been tested for usability and verifiability with voters who are representative of the general population, as well as voters with disabilities, and voters whose preferred language is other than English.

Principle #7: Auditable
PVRs contain features to support post-election audits, including risk-limiting audits, as well as recounts.

Principle #8: Private
PVRs protect the privacy of the voter.

Principle #9: Cost-Effective
PVRs are produced on paper that can be easily sourced by election officials at a modest cost.

Principle #10: Reliable and Scalable
PVRs are capable of supporting the types and scale of elections commonly administered in the United States and other global democracies.

While the OSET Institute research interests are global in nature, this paper addresses the topic of Printed Vote Records from a US perspective, in light of recent US-centric issues with their design, usability, and other integrity-related matters.

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1. Context

Following the U.S. Intelligence Community's unequivocal conclusion[1] that Russia attempted to interfere with the 2016 Presidential Election, ensuring the integrity of elections in the U.S. is appropriately a topic of great focus. Central to this discussion have been the topics of transparency and auditability, and more specifically the added assurance that comes from capturing voter choices on devices that produce a durable, voter-verifiable paper record of the voter's selections. Conversely, paperless DRE devices that cannot be audited are rapidly falling out of favor and are rightly being replaced by voting solutions that produce a "paper trail."

The term "paper trail" is intentionally broad and encompasses a variety of implementations that could potentially meet the bar of voter-verifiability and post-election auditability. Various types of "paper trails" include:

- Hand-marked Ballots: these are traditional paper artifacts with ovals or boxes that are "bubbled in" with a pen;
- Machine-marked Ballots: these are traditional artifacts whose form and content is essentially identical to hand-marked ballots (and typically produced by accessible ballot marking devices (BMDs));
- VVPAT Devices: these are part of direct record electronic (DRE) machines (*which are increasingly rare*) that produce a form of a paper record; and
- Summary Vote Records: these are paper records produced by "hybrid" devices that have a digital interface paired with a printer that produces a physical (paper) record of the voter's selections.

Summary Ballots or "Summary Vote Records" generated by hybrid marking devices are a newer, alternative distinct from *both* traditional ballots *and* older-generation DREs with VVPATs. They differ from traditional ballots insofar as they do not contain marked target areas (e.g. ovals or boxes), and instead contain only machine-printed text of the voter's choices. Furthermore, they list only the voter's choices and not all possible options on the ballot (hence the term "Summary"). Finally, voters must take their hybrid printed vote records from the marking device to a separate scanner or ballot box, in order to cast the vote (i.e. similar to traditional ballots), unlike DREs that store votes electronically and retain their paper audit trails in a secure container integrated with the voting device.

Summary Paper (Vote) Records that capture a voter's selections in human-readable form are the subject matter of this Paper.

In a security-conscious age where paper trails are increasingly considered the "minimum bar" for voting devices, summary paper records are proliferating at a rapid pace from a variety of voting system manufacturers. Hybrid devices that produce summary paper records are a popular option for some election administrators, particularly for jurisdictions that insist upon "touchscreen voting" or "machine-style voting," and who resist the use of hand-marked ballots as "a step backward," (*though debatable that proposition may be*).

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[1] https://www.dni.gov/files/documents/ICA_2017_01.pdf

Indeed, at the time of developing this Paper, the state of Georgia's *Secure, Accessible & Fair Election (SAFE) Commission*, which is charged with assessing options to replace the state's paperless and error-prone DRE system, has recommended[2] in a 13-3 vote that the state adopt higher-cost touchscreen "hybrid" marking devices, rather than lower-cost traditional ballot solutions.

In addition to the fact that touchscreen-style voting remains popular with many election administrators, voting system manufacturers also welcome the "equipment-heavy" implementations associated with this voting model, as such allow vendors to sell far more voting units than would be associated with traditional paper ballot implementations (which for example, typically require only one optical scanner and one accessible ballot marking device per precinct), thereby resulting in more up-front and recurring revenue from the sales contract.

1.1 Purpose and Objectives

This Paper focuses on Printed Vote Records, prompted by the fact that the diversity of implementations in the marketplace indicates an emerging technology in need of uniform design principles, best practices, and additional research. The relatively fast pace at which hybrid devices with "summary ballots" are being brought to the market raises the risk and likelihood that some designs may adversely impact verifiability, usability, accessibility, privacy, cost-effectiveness, and other important values in voting and election administration.

Here then, are the objectives of this Paper:

1. Describe and explain how "hybrid" marking devices work, and present representative sample formats of common paper record styles.
2. Summarize the commercial offerings that are currently available from proprietary vendors.
3. Identify the issues and design challenges reflected in current implementations of hybrid paper records.
4. Provide principles and guidelines for the form and content of Printed Vote Records (PVRs).
5. Identify areas for future research.

1.2 Scope

This Paper is focused on the form and content of summary (i.e. choices-only) Printed Vote Records, which have not been extensively studied. Conversely, discussions about the overall user experience for hybrid ballot marking devices, including topics such as user interface design, hardware industrial design, and accessibility are outside the scope of this paper. Similarly, a discussion of best practices for traditional ballot design is also beyond the scope of this paper. Over the past 10 years, a wealth of research and reporting has been produced on best practices for user interface design, human factors, and traditional ballot design. The author encourages readers interested in those topics to review resources from the *National Institute of Standards and Technology* (NIST), the *Center for Civic Design*, and the *Brennan Center for Justice*,

[2] https://www.ajc.com/news/state--regional-govt--politics/georgia-panel-backs-new-voting-machines-over-hand-marked-paper-ballots/feF5QiAwnzl2l3BK055dtI/

among many others. The OSET Institute may produce additional materials incorporating these works another time.

1.3 About Definitions and Terminology

For purposes of this Paper, a Printed Vote Record, or PVR, is defined as an auditable, durable paper record of voter choice selections produced by an electronic marking device. This terminology is by design, because common phrases like "*summary ballot*" or "*paper cast vote record*" do not do justice to some of the nuance and complexity associated with these paper artifacts.

It is important that PVRs should *not* be referred to as "ballots" for a variety of reasons. Notwithstanding casual (and typical) linguistic usage, such records are not "ballots," strictly speaking, because most states in the Union have particular specifications for (traditional) ballots that these hybrid-style records do not meet. For example, it is not uncommon for state election codes to specify requirements for the content of a ballot header, including its official label (e.g., "OFFICIAL BALLOT"), the jurisdiction name, minimum font sizes, possible placement of graphic seals, required paper sizes, and so forth. However, Printed Vote Records produced by today's hybrid marking devices often have their composition and design constrained by the technology that the vendor has selected to print the paper. Vendors may choose, for example, to employ embedded thermal on-demand printers that use smaller paper sizes than traditional ballots; and those design choices in turn constrain the placement and layout of text on the final output. Most importantly, unlike traditional ballots that list all choices (or "target areas") for each contest, Printed Vote Records summarize only the selection(s) that voters actually chose for each contest. For all of these reasons, Printed Vote Records produced by hybrid marking devices often look and feel different from traditional ballots, and particularly in polling places where both are used, it is important to maintain the distinction— especially because different paper formats can result in "segregated" and "unequal" ballots that may compromise the privacy and anonymity of some voters (e.g. if only voters with disabilities use a hybrid accessible marking device that prints on smaller-size cards).

While some states (notably California, for example, in Election Code Sec. 305.5 [3]) have admirably attempted to recognize these nuances and codify a distinction between traditional ballots and these newer-style paper records, the term "*paper cast vote record*" is also a misnomer, due to the inclusion of the word "*cast*." Federal Voluntary Voting System Guidelines (VVSG) actually prohibit marking devices from storing records of voter selections; as a result, the vote cannot be said to be "cast" until the paper is inserted in a *separate* device for tabulation (typically an in-person precinct scanning device, or a high-speed scanner at a central elections office). Stated another way, because hybrid marking devices are essentially digital "pens" that simply mark choices, the cast vote is distinct from the PVR itself. Printed Vote Records are not considered "cast" until they are scanned, which converts the choices on paper into an electronic cast vote record (CVR).

[3] https://www.lawserver.com/law/state/california/codes/california_elections_code_305-5

In summary, the term Printed Vote Record (PVR) emphasizes that the record is:

1. Paper;
2. Machine-printed;
3. Indicative of a voter's intended "vote" in each contest;
4. Distinct from the digital ***cast*** vote record that is used for purposes of automated tabulation; and
5. Distinct from a traditional "ballot."

It is noteworthy that the *Glossary* in the United States Election Assistance Commission's *Voluntary Voting System Guidelines (VVSG)* v. 1.1 (2015, the most recent version adopted) does *not* include a term that specifically addresses these alternative paper formats.

1.4 Outline

The remainder of this Paper assesses current implementations of Printed Vote Records from commercial vendors, identifies relevant design issues, and offers guidance for future development.

- Section 2 explains how hybrid marking devices generally work, and provides information about current offerings from proprietary vendors.
- Section 3 identifies and summarizes important questions and concerns associated with current designs.
- Section 4 offers high-level principles and guidelines for the design of Printed Vote Records.
- Section 5 identifies areas for future research.

2. Overview of Hybrid Marking Devices

"Hybrid" marking devices can be thought of as modern-day successors to first-generation DREs with voter-verifiable-paper-audit trails (VVPATs). Hybrid devices are similar in some ways to those older-generation devices (*and indeed, are sometimes incorrectly referred to as "DREs"*), because both share the combination of an electronic display, which presents contest choices to be marked, and a paper record output. With DREs, since those devices store electronic cast vote records, the VVSG requires that their VVPAT records be secured inside an enclosure that is inaccessible to the voter, and that is retained only by election administrators for post-election recounts and/or audits. The purpose of this requirement is to prevent voters from being able to exit the polling place with a "receipt" that proves how their vote was cast, as that would create the possibility of "vote selling/vote buying," which is a form of voter fraud. Accordingly, with a DRE + VVPAT, the voter marks and casts the ballot on the same device; no other steps are required for the voter, and the voter never touches the paper trail.

In contrast, as noted earlier, hybrid-marking devices differ from DREs in one crucial way: *they do not store cast vote records, as DREs do*. At the conclusion of the marking session, hybrid devices present voters with a summary of their choices for review (similar to a DRE), and after the review is complete, the voter prints a paper record of those choices. Unlike the DRE voting method, after printing the paper record, the voter physically collects the printed vote record and *he/she must submit the paper elsewhere to actually cast the vote* (again, typically a precinct scanner or a secure ballot box).

Below is a sample generic workflow (or "process flow" as illustrated in Figure 1) for voting with most hybrid device implementations. Hybrid devices may or may not include fully accessible options, such as audio-visual features for voters who are blind or visually impaired, or features for those who have dexterity impairments.

A. Voter checks-in at polling place. The voter's eligibility to vote is confirmed with a manual or digital poll book, and the voter is posted.

B. The ballot style is activated on the hybrid device. Based on the voter's residence address, the proper ballot style is identified in the poll book, and the hybrid-voting device is activated with the appropriate ballot style. This may be done manually by a poll worker or the voter, or in automated fashion, with information from the pollbook check-in. Depending on the specific type of device, different manufacturers have different requirements for voters to insert and manage blank paper, which may be in sheets, cards, or on-board rolls.

C. The voter marks the electronic ballot. The voter uses the marking device's touchscreen or accessible options to mark choices for each contest on the ballot.

D. The voter reviews ballot choices. The voter reviews a "summary page" on the hybrid device, which lists each contest on the voter's ballot, the choice(s) for each contest, and any "no selection" contests. (Note: Today's hybrid devices all prevent voters from being able to mark too many choices in any contest, i.e. "over-voting.")

E. The voter selects when to print the vote record. Most hybrid devices instruct the voter to print only after the review is complete, as changes cannot be made once the record has been printed.

F. The voter physically collects the Printed Vote Record. Hybrid devices typically return a printed card, a printed sheet of paper, or a long "tape" from roll-style installed on the device.

G. The voter submits the vote on a separate scanning device, or in a secure ballot box. Modern-day precinct scanners or high-speed scanning software can also identify possible voter "mismarks," such as contests with no votes, to support "second chance corrections" before the vote is cast and recorded.

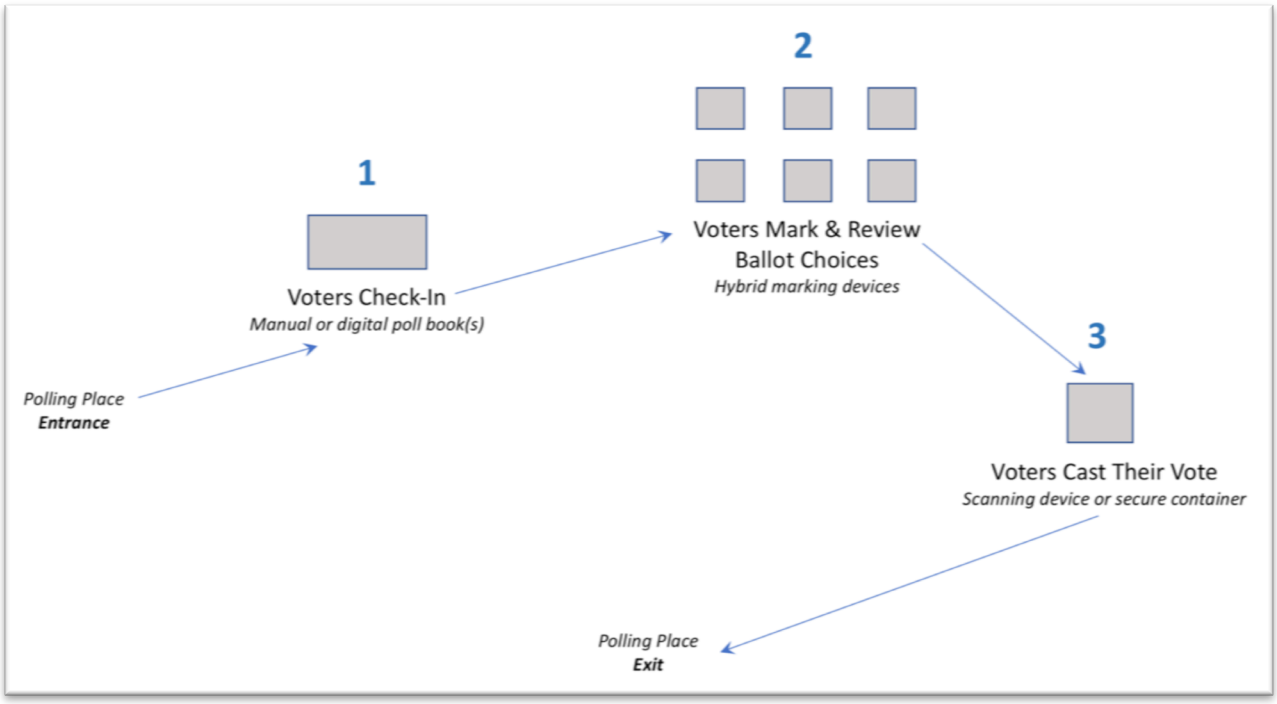


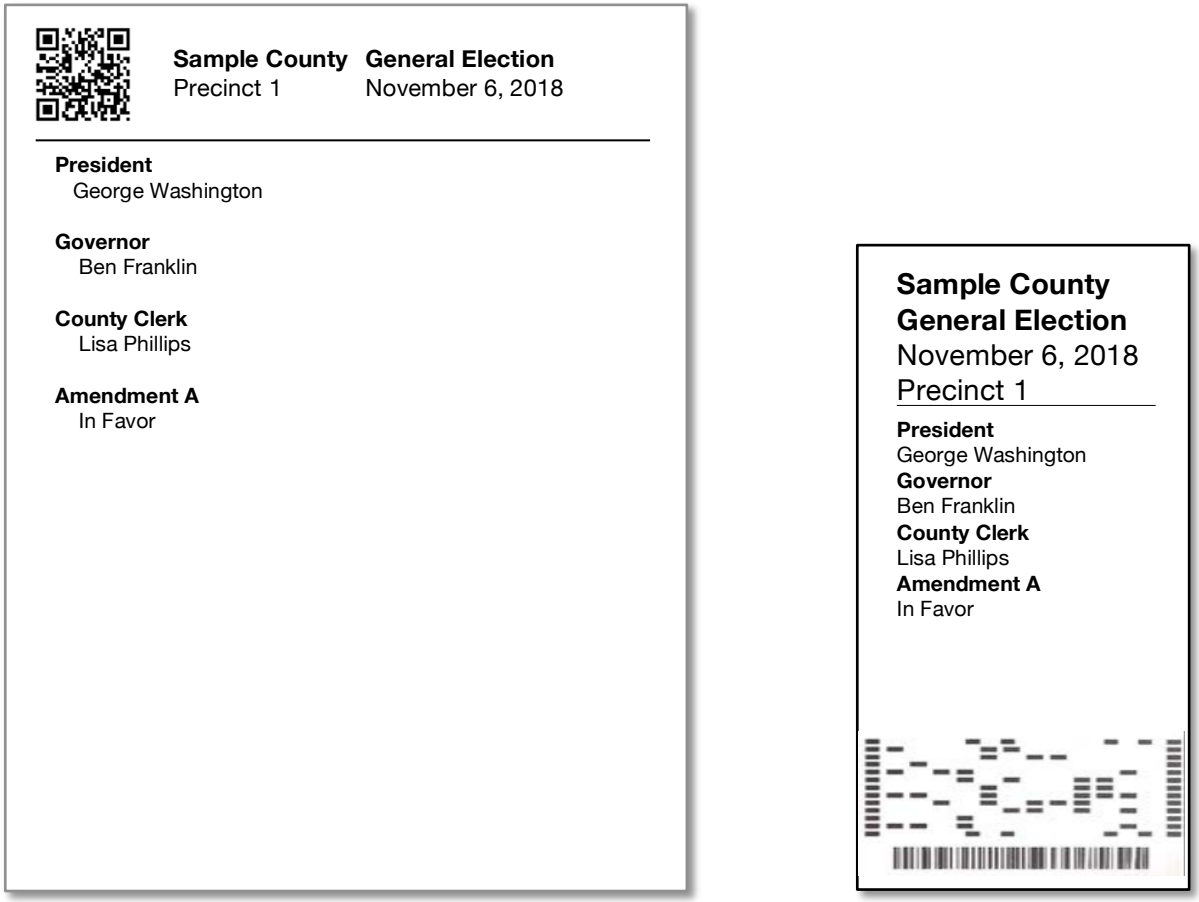
Figure 1. Process Flow

2.1 Overview of Printed Vote Records

While the content, format, and design of Printed Vote Records varies across different voting system manufacturers, some features are common to most. Printed Vote Records typically contain the following classes of information:

1. **Header** (Jurisdiction name; Election title; Date; Precinct or ballot style ID);
2. **Contest titles**;
3. **Voter's choice**(s), per contest;
4. **QR codes** or barcodes, for purposes of automated processing (Note: some vendors embed voter selection data in non-human-readable QR codes or barcodes, and others do not; designs vary);

Generic examples of two common styles are shown below.



PVR Sheet on standard size paper

PVR Card on narrow stock

Figure 2. Common Generic PVR Styles

2.2 PVR Designs Currently Commercially Offered

A variety of commercial vendors have developed and attained federal certification for different implementations of hybrid devices that produce Printed Vote Records. These products show diverse approaches and features associated with information design, verifiability, and printing technologies. In this Section on the next several pages, in absence of any comparative assessments, using publicly available visual elements for each vendor solution, we illustrate the need for more research, testing, and guidance to develop uniform best practices in the future.

Election Systems & Software (ES&S) ExpressVote™

- This system is currently VVSG 1.0-certified by the U.S. Election Assistance Commission (EAC)
- This "Ballot marking device" (BMD) is typically paired with the ES&S DS200 precinct optical scanner

PVR Information Design

- Contest titles are right justified (*note that some are truncated*)
- Voter choices are left-justified, and preceded by leading dots
- Single-spaced lines for contest titles and voter selections (*i.e., no white space in-between lines*)

00000111
ELECTION: GENERAL ELECTION
ELECTION DATE: 11/08/2016
PRECINCT: 748-050 SPG 15 050

U.S. PRESIDENT AND U.S. VICE PRESI•REP DONALD J. TRUMP
U.S. SENATE----------REP SENATOR JOHN BOOZMAN
U.S. CONGRESS DISTRICT 03•REP CONGRESSMAN STEVE WOMACK
STATE REPRESENTATIVE DISTRICT 89 DIS•REP JEFF WILLIAMS
COUNTY JUDGE----------REP JOSEPH K. WOOD
COUNTY ASSESSOR----------REP ASSESSOR RUSSELL HILL
CIRCUIT CLERK---------REP CIRCUIT CLERK KYLE SYLVESTER
CONSTABLE DISTRICT 01 DISTRI•REP CONSTABLE JOHN DUGGAR
MAYOR SPRINGDALE----------MAYOR DOUG SPROUSE
CLERK/TREASURER SPRINGDALE----------NO SELECTION MADE
ALDERMAN WARD 1 POSITION 2 SPRINGDALE--------ERIC FORD
ALDERMAN WARD 2 POSITION 2 SPRINGDALE-------RAY DOTSON
ALDERMAN WARD 3 POSITION 2 SPRINGDALE------JEFF WATSON
ALDERMAN WARD 4 POSITION 2 SPRINGDALE-----JEREMY LYNCH
ISSUE NO. 1----------FOR ISSUE NO. 1
ISSUE NO. 2----------FOR ISSUE NO. 2
ISSUE NO. 3----------NO SELECTION MADE
ISSUE NO. 4----------FOR ISSUE NO. 4
ISSUE NO. 5----------FOR ISSUE NO. 5
ISSUE NO. 6----------FOR ISSUE NO. 6
ISSUE NO. 7----------FOR ISSUE NO.7
UNOPPOSED CANDIDATES----------NO SELECTION MADE

PVR Verifiability and Tabulation

- Voter choices are encoded in individual "voter selection barcodes"
- To tabulate, the ES&S EVS voting system interprets (deciphers) barcodes on the scanned PVR cards

PVR Printing and Consumables

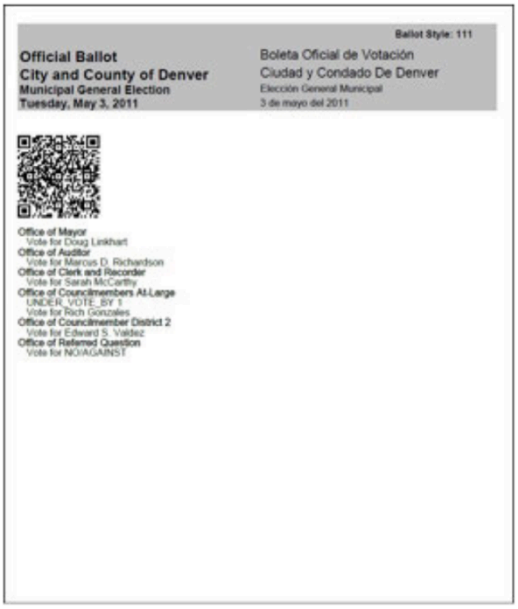
- ExpressVote prints on proprietary thermal cardstock available from ES&S
- ExpressVote prints PVRs from an internal printer.
- Thermal cardstock is 4.25" wide and available in lengths up to 19.0"

Dominion Voting Systems ImageCast X™

- This system is currently VVSG 1.0-certified by the U.S. Election Assistance Commission (EAC)
- This device is commonly configured as a BMD (can also be configured as a DRE with VVPAT).[4]

PVR Information Design

- Contest titles are stacked above voter choices; contest titles are boldface
- Voter choices are slightly indented beneath contest titles
- Single-spaced lines for contest titles and voter selections (i.e. no white space in-between lines)



Ballot Style: 111

Official Ballot
City and County of Denver
Municipal General Election
Tuesday, May 3, 2011

Boleta Oficial de Votación
Ciudad y Condado De Denver
Elección General Municipal
3 de mayo del 2011

Office of Mayor
Vote for Doug Linkhart
Office of Auditor
Vote for Marcus D. Richardson
Office of Clerk and Recorder
Vote for Sarah McCarthy
Office of Councilmembers At-Large
UNDER_VOTE_BY 1
Vote for Rich Gonzales
Office of Councilmember District 2
Vote for Edward S. Valdez
Office of Referred Question
Vote for NO/AGAINST

PVR Verifiability and Tabulation

- Voter choices are embedded in a 2D barcode that is readable only by Dominion's ImageCast tabulators
- To tabulate, the Dominion Democracy Suite voting system interprets the QR codes on the scanned PVRs

PVR Printing and Consumables

- ImageCast X prints PVRs on commercial-off-the-shelf (COTS) standard-size paper (8.5 x 11 or 8.5 x 14)
- Prints PVRs to attached COTS laser printer (HP printer)

[4] "DRE" stands for Direct Recording Electronics; "VVPAT" stands for Voter Verifiable Paper Audit Trail.

Unisyn Voting Solutions FreedomVote Tablet (FVT)

- This system is currently VVSG 1.0-certified by the U.S. Election Assistance Commission (EAC)
- BMD, typically paired with Unisyn's OpenElect optical scanner (OVO)

PVR Information Design

- Contest titles are stacked above voter choices
- Voter choices are slightly indented beneath contest titles
- Single-spaced lines for contest titles and voter selections (i.e. no white space in-between lines)

PVR Verifiability and Tabulation

- Voter choices are embedded in barcodes that are readable by OpenElect tabulators
- To tabulate, the Unisyn OpenElect voting system interprets the barcodes on scanned PVRs

PVR Printing and Consumables

- FreedomVote prints PVRs to an integrated, roll-fed 3.25" wide (82.5 mm) wide thermal receipt printer
- The thermal roll stock is proprietary and is only available through Unisyn Voting Solutions

2.3 Future Hybrid Systems—Not Yet Available

Information presented below is based on open source information at the time of writing.

Hart InterCivic Touch Duo

- Not yet certified by the federal U.S. Election Assistance Commission (EAC)
- The EAC website indicates that Hart InterCivic's Verity Voting v. 2.3 system is currently "under test."

PVR Information Design

- Unknown; no public information is available.

PVR Verifiability and Tabulation

- According to public transcripts of Georgia SAFE Commission meetings,[5] a Hart representative indicates that the Verity Voting system tabulates PVRs using optical character recognition. The same representative indicates that QR codes on the PVR do not contain voter choice information, and are used only for purposes of validating the PVR.
- In recent news stories,[6] a Hart representative repeated the claim that to tabulate PVRs, their optical scanners use optical character recognition of the human-readable text—*not* QR codes.

PVR Printing and Consumables

- Hart's online brochure [7] indicates that Touch Duo prints on full-size, non-proprietary stock.

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5 http://sos.ga.gov/admin/uploads/SAFE Commission Transcript 8.30.18.pdf

6 http://www.gpbnews.org/post/look-machines-could-replace-georgia-s-aging-voting-system

7 https://www.hartintercivic.com/wp-content/uploads/TouchDuoProductBriefTX.pdf

LA County "Voting Systems for All People" (VSAP)

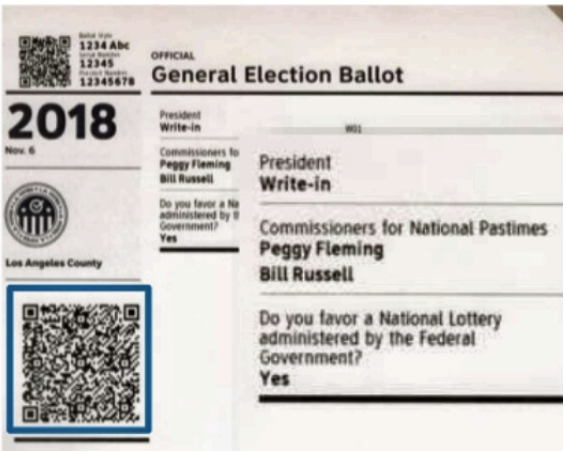
VSAP Ballot Marking Device

- Not yet certified by the California Secretary of State

PVR Information Design

- Contest titles are left-justified
- Voter choices are left-justified and are immediately below contest titles
- Voter choices are in boldface
- Lines separate each pair of contest titles and choices
- White space (chunking) is used to separate each pair of contest titles and choices

PVR Verifiability and Tabulation



- According to information included in public testimony[8] of Kenneth Bennett, Program Manager, VSAP — Los Angeles County Registrar-Recorder/County Clerk, the VSAP system embeds codes associated with voter selections in a QR code.
- To tabulate, the VSAP voting system interprets QR codes on the scanned PVRs.
- According to information included in Mr. Bennett's written testimony, Los Angeles County considered designs that would tabulate based on optical character recognition of the human-readable text, but the County ultimately elected not to use that technology for tabulation purposes.

PVR Printing and Consumables

- According to LA County's Request for Information[9] for the VSAP project, "*The [integrated thermal] printers required for the BMD will print on a larger form sheet of paper (8"x 11" and 8" x 13.25") and thicker paper (143µm). The thickness requirement derives from the handling, scanning, packing, shipping and 2-year storage requirement for the paper ballots.*"

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8 https://lhc.ca.gov/sites/lhc.ca.gov/files/CurrentStudies/VotingEquimentSecurity/WrittenTestimony/BennettJuly2018.pdf

9 http://vsap.lavote.net/wp-content/uploads/2017/07/RFI-ISD.pdf

3. Findings—Design Issues and Challenges

A review of the previous section's diverse implementations reveals these findings:

- Information design features for Printed Vote Records vary widely.
- With the exception of one vendor's upcoming hybrid device that employs optical character recognition of voter choices, all implementations embed voter choices in obfuscated barcodes or QR codes for purposes of tabulation; these barcodes are not directly verifiable by voters.
- In terms of the voting experience, the comparative usability (effectiveness, efficiency, and satisfaction) of competing PVR designs is unknown. Although each vendor with an EAC-certified system was required to submit usability testing results at the time of their application for certification, no testing has ever directly compared different PVR designs, and in any case, usability testing reports submitted to the EAC are not always publicly available, so it is impossible to assess which features of different PVRs are most effective and desirable.

Each of these findings indicates a variety of unsolved design challenges and questions that should be addressed in future development cycles for Printed Vote Records, based on additional fact-based research.

3.1 Information Design

As illustrated in the previous section, there are several methods to present contest titles and voter choices on a summary printed vote record. Some designs place titles and choices on a single line, separated by leading dots; some designs stack titles and choices; and designs vary in the use of justification and indentation. Furthermore, some designs employ boldface to emphasize contest titles and/or choices.

It should also be noted that operational considerations associated with the desire of election administrators to minimize the likelihood of multi-sheet PVRs complicate the task of information design. Generally speaking, election officials prefer single-sheet paper records with dense amounts of information, to forestall the complex task of potentially having to reconcile multiple-sheets and vote counts. In addition, the cost and perceived burden of providing additional blank paper supplies to polling places (i.e. if ballots are longer) is regarded as a difficulty to be avoided.

Unfortunately, those valid operational considerations create friction with best practices for information design. To cite just one example, note that most of the commercialized PVR designs do not have blank white spaces, or blank lines, in between each contest. This results in PVRs that are harder to read. Use of additional white space or "chunking" would result in information that is easier for voters' eyes to trace and review, resulting in more robust and meaningful verification of voter intent. Again, the absence of extra white space is due to the need to include as many voter choices on a single sheet of paper as possible. Similarly, selecting appropriate minimum font sizes (especially in accordance with diverse state certification requirements) is a difficult balance of usability and operational efficiency.

Finally, all of these considerations are constrained by the basic issue of what size and style of paper voters find easiest to use. Do voters prefer full-size sheets of COTS paper (e.g. letter or legal size), or do they prefer smaller sizes with narrower columns to read? Note that at least one PVR design, based on a narrow 4.25" card, actually *truncates* the printed contest title, which adversely impacts a voter's ability to accurately verify selections.

To summarize, the OSET Institute believes four questions in particular (among several) about PVR information design deserve additional exploration:

1. What size of paper is optimal?
2. What font sizes are optimal?
3. What is the most effective and usable presentation of contest titles and voter choices?
4. What templates achieve the necessary balance between usability and operational efficiency for election officials?

3.2 Transparency and Voter-Verifiability

The transparency and verifiability of printed vote records by voters has recently become a topic of increased scrutiny and controversy. Some voters express uneasiness (*if not outright distrust*) at the prospect of their vote being tabulated by an automated system that interprets QR codes or barcodes whose contents are not transparent or easily reviewed. In the absence of seeing a voter-produced mark inside an oval or a checkbox (as on a traditional ballot), voters must trust that the voting system correctly "sees" or "reads" their intended choices – and of course, if the contents of a barcode cannot be seen, then the possibility exists that through technical error (i.e. software "bugs") or due to malicious activity, something *other than the voter's intended choice* might be recorded.

> *In short, non-transparent barcodes or QR codes introduce a new class of security vulnerabilities.*

In fairness, using software to interpret QR codes or barcodes on a PVR from a hybrid device is akin to using software to interpret the location of voter marks on a traditional ballot. Whether a voting system scans paper digitally or optically (i.e. using columns and timing marks), the fact remains that automated processing and interpretation of voter choices on a printed piece of paper necessarily relies on technology whose inner workings may not be apparent to the voter.

On the other hand, advocates and voters who express a preference for hand-marked ballots over hybrid marking devices may be on to something. Hand-marking a ballot (or using accessible technology to mark a ballot) has a certain immediacy to it that is different than the hybrid use case. Marking a traditional ballot requires the voter to ***focus*** on the ballot ***itself***, knowing that his/her marks will be directly reflected in the output. The overall experience feels less "mediated" by technology than the hybrid use case, and hence more transparent, understandable, and trustworthy.

The important lesson is that achieving trust and securing the integrity of the vote is more difficult when voters are working with a device that they cannot understand because its workings are not transparent.

The best practice for Printed Vote Records is not to embed voter selections in non-transparent formats, and to tabulate PVRs based on the same human-readable text that the voter sees (or hears, in the case of accessible audio ballots). As noted above, this appears to be an emerging trend in the newest hybrid systems; time will tell if it becomes a new standard (as it should).

3.3 Usability

Another design goal for Printed Vote Records should be to facilitate and encourage voters to conduct meaningful reviews of the PVR before casting their vote, to ensure that their choices are recorded in accordance with the voters' intent. Recent research by DeMillo,[10] Kadel, and Marks[11] presents preliminary evidence suggesting that most voters will *not* attempt to verify summary PVRs, even when they are directed to do so. Furthermore, their research found that statistically significant numbers of voters either fail to recognize errors in records presented for verification, or they fail to recognize that the records presented for verification were *not* the ones they cast. These results are troubling. Accordingly, the OSET Institute seeks answers to these questions:

1. What prevents voters from consistently verifying Printed Vote Records produced from a hybrid-marking device?
2. Are there optimized features in the form or content of PVRs that can encourage voters to actually verify their choices, and to identify possible mistakes?
3. What features of PVR design templates have the greatest positive impact on effectiveness, efficiency, and satisfaction?
4. How does the rate of voter-verification of machine-marked PVRs compare to the rate of voter-verification of hand-marked traditional ballots? Are the rates markedly different? Why or why not? Are failures due to natural aspects of human psychology, or are they markedly helped or hurt by different formats of paper media?

3.4 Operational and Supply Chain Concerns

The commercial implementations of PVRs illustrated in Section 2 *supra*, reveal different uses of technology and paper that have direct impacts on costs and ease of use for election administrators. For example, some hybrid devices use proprietary paper stock that is only available from the voting system vendor, thereby placing jurisdictions in a position of dependency, subject to the vendor's sole-source pricing for consumables. In contrast, other systems use commercial-off-the-shelf (COTS) paper and COTS printers that result in greater independence for election officials, as they have the ability to shop for the most cost-effective suppliers. The cost of hybrid voting supplies and the ease with which they can be sourced are important considerations that can greatly help or hurt an election official's ability to efficiently manage the availability and overall readiness of voting system components. All things equal, PVR design features that prevent "vendor lock-in" and that support self-sufficient operations for election officials are *most* desirable.

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[10] Dr. Rich DeMillo is a Strategic Board Advisor to the OSET Institute

[11] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3292208

4. Principles and Guidelines for Printed Vote Records

Based on current technology trends and market requirements, and with a particular emphasis on enhancing the overall integrity of the voting experience, this paper highlights the following OSET Institute principles for the design and development of machine-marked Printed Vote Records.

Principle #1: Transparent

Printed Vote Records (PVRs) display and tabulate voter choices in a manner that is understandable to the voter.

Guidelines for Principle #1:

1. The human-readable contest title and voter choice information on the PVR is in plain text.
2. The human-readable contest title and voter choice information does not require additional information, such as a codebook, lookup table, or other information, to unambiguously determine the voter's ballot choices.
3. Any non-human-readable information on the PVR is presented in a fully disclosed public format.

Principle #2: Voter-Verifiable

Printed Vote Records (PVRs) allow voters to directly verify the same human-readable text that the voting system uses for purposes of tabulation.

Guidelines for Principle #2:

1. Voter choice records are *not* embedded in QR codes or barcodes.

Principle #3: Secure

Printed Vote Records (PVRs) ensure the integrity of the vote and do not allow voter choices to be changed without detection.

Guidelines for Principle #3:

1. PVRs include features that allow the voting system to validate their authenticity (i.e. they are valid PVRs associated with the election being conducted).
2. After PVRs have been printed, they are not capable of being changed without the scanning and tabulation system detecting that the record was modified after printing.
3. PVRs reduce their attack surface through technical controls.

Principle #4: Usable

Printed Vote Records (PVRs) support a voter's ability to review his/her printed choices for accuracy before the vote is cast.

Guidelines for Principle #4:

1. PVRs employ best practices for information design, including features associated with composition, typeface, font size, boldface, chunking, and plain language.

Principle #5: Accessible

Printed Vote Records (PVRs) are accessible to the broadest possible range of voters.

Guidelines for Principle #5:

1. PVRs are accessible to voters with disabilities and are capable of being reviewed using assistive technology (e.g. text-to-speech conversion, directly from the printed page).
2. PVRs support federal and state requirements for voters whose preferred language is other than English.

Principle #6: Tested

Printed Vote Records (PVRs) have been tested for usability and verifiability with voters who are representative of the general population, as well as voters with disabilities, and voters whose preferred language is other than English.

Guidelines for Principle #6:

1. PVRs have been tested to ensure that their form factor can be managed and scanned by the broadest possible range of voters.
2. PVRs have been tested to ensure that their features encourage voters to verify the PVR.
3. PVRs have been tested to ensure that voters are confident and satisfied that their choices are listed in the manner intended, and that any errors can be easily identified.

Principle #7: Auditable

Printed Vote Records (PVRs) contain features to support post-election audits, including risk-limiting audits, as well as recounts.

Guidelines for Principle #7:

1. PVRs are capable of having their images digitally stored for purposes of post-election audits.
2. PVRs include features that allow election administrators to identify the physical location where they were processed (e.g., a specific precinct scanner, high-speed scanner, "bin," or "batch.")
3. PVRs include features that allow auditors to associate a single unique Printed Vote Record with its corresponding digital image and electronic Cast Vote Record (CVR), as tabulated in the voting system.

4. PVRs support recounts, including the ability of election officials to perform recounts only on specific contests.

Principle #8: Private

Printed Vote Records (PVRs) protect the privacy of the voter.

Guidelines for Principle #8:

1. PVRs do not include features that can personally link the voter's identity to voter choices.

Principle #9: Cost-Effective

Printed Vote Records (PVRs) are produced on paper that can be easily sourced by election officials, at a modest cost.

Guidelines for Principle #9:

1. PVRs are printed on paper stock that is non-proprietary and available from commercial sources.
2. PVRs are printed on durable paper that can withstand extensive physical handling (e.g., by voters, election officials, or auditors.)
3. PVRs are printed on durable paper that has a shelf life appropriate for pre-election warehouse storage and post-election retention, in accordance with relevant statutes.

Principle #10: Reliable and Scalable

Printed Vote Records (PVRs) are capable of supporting the types and scale of elections commonly administered in the United States and other global democracies.

Guidelines for Principle #10:

1. PVRs support a broad range of election types (e.g., winner-take-all, proportional, general elections, primaries, special elections, mixed systems, etc.)
2. PVRs support a broad range of logical system limits, including the needs of even the largest jurisdictions (i.e. many contests, associations, ballot styles, etc.)

5. Topics for Future Research

After reviewing currently available implementations of Printed Vote Records (PVRs), and with consideration for the principles and guidelines presented above, the OSET Institute believes that future research efforts in the following areas would be highly valuable not only to the U.S. election administration community, but to the nation as a whole, and possibly on a global basis:

1. Comparative, iterative usability testing for various Printed Vote Record designs. As noted above, different implementations of PVR designs have never been directly compared and tested to ascertain which features contribute to accuracy, effectiveness, efficiency, and voter confidence.
2. Best practices and uniform templates for Printed Vote Records. In the same way that the EAC and the American Institute of Graphic Arts (AIGA) collaborated in the previous "*Design for Democracy*" project[12] for information design for DREs and paper ballots, the project should be extended and reinvigorated to address these new forms of Printed Vote Records.
3. The applicability of optical character recognition (OCR) technology to future Printed Vote Record designs. As noted earlier, tabulation directly from human-readable text, while less common, is emerging as a firm requirement for voter-verifiability. Additional research can help to identify ongoing design questions, limitations, and mitigations.
4. Alternative printing and paper technologies. Currently, thermal printing, which is a mature technology, is favored among most hybrid device manufacturers. However, other forms of emerging technology may be advantageous in the future.
5. Comparisons of elections administered with traditional hand-marked ballots versus hybrid ballot marking devices. In a cybersecurity-conscious era, when foreign nation-state actors pose threats to the U.S.'s critical democracy infrastructure, it is appropriate to investigate and compare the overall costs and benefits of these two approaches to voting with "paper trails." While the author welcomes the overall trend toward a baseline market expectation that voting systems should, at a minimum, have auditable and durable paper records, traditional ballot voting and hybrid BMD touchscreen-style voting differ in several important respects:
    a. Verification of paper records. As noted above, hand marking a ballot requires a kind of intentionality (akin to "self-verification") that differs from hybrid-style voting. Proponents of hybrid-style voting would benefit from additional research on the frequency and accuracy with which voters actually verify Printed Vote Records.
    b. Security. Polling places that provide hybrid devices for all voters (instead of pens to mark paper ballots) have a much larger attack surface, because overall voting system operations depend on vastly more hardware and software than more traditional methods. Furthermore, as noted earlier, virtually all implementations to date of hybrid technology tabulate Printed Vote Records based on non-transparent QR codes or barcodes that introduce additional security vulnerabilities.

[12] https://www.aiga.org/globalassets/migrated-pdfs/eac_effective_election_design

c. Availability and continuity of operations. The larger technology "footprint" of hybrid-style voting for all voters has important implications for ongoing operations at polling places. If power is interrupted, or if poll workers make mistakes in setting up many hybrid devices, and if backup (traditional) paper ballots are not supplied to the polling place, it is possible for voting to be significantly disrupted, or to stop altogether. Such conditions could result in frustrated voters leaving the polling place without casting a ballot, thereby disenfranchising them. In contrast, all that is required for traditional paper ballot voting to continue is the availability of paper ballots and pens. (Even if a precinct scanner were disabled due to a power outage, for example, marked ballots can still be collected in a secure ballot box, to be tabulated at a later time.) For all of these operational reasons, the comparative benefits and vulnerabilities of hand-marked ballots vs. hybrid solutions should be carefully assessed.

d. Total cost of ownership (TCO). As noted earlier, precinct-style voting with traditional paper ballots typically requires significantly less equipment than hybrid-style implementations. Most precincts require only one scanner and one accessible ballot marking device, while hybrid implementations may include 3 to 6 hybrid devices in a single polling place (or perhaps far more; busy precincts may have 10 to 12 units, and many dozens of devices may be used in large Early Voting or Election Day convenience voting "supercenters"). The significant up-front capital expenditure, coupled with recurring annual license fees that jurisdictions must pay to commercial vendors to use hardware and software, results in very different overall TCO for states, counties, and election officials. To cite just one recent example,[13] news outlets reported that in Georgia's future statewide voting system implementation, the difference between hand-marked ballot solutions and hybrid solutions is approximately $30 million versus $100 million, respectively.

Assessing the pros and cons of more expensive hybrid technology as compared to lower-cost paper ballot voting methods is critical if public stewards of taxpayer dollars are to choose voting technology wisely — particularly in light of open questions about verifiability, security, and operational efficiency. This paper aims to advance that discussion. U.S. national security and the health of its democracy depend on it.

[13] https://www.ajc.com/news/state--regional-govt--politics/georgia-panel-backs-new-voting-machines-over-hand-marked-paper-ballots/feF5QiAwnzl2l3BK055dtI/

6. References

1. American Institute of Graphic Arts (AIGA), *Top 10 Ballot Design Tips (for Designers)*. https://www.aiga.org/aiga/content/why-design/design-for-democracy/top-10-ballot-design-tips-for-designers/
2. American Institute of Graphic Arts, *Top 10 Election Design Guidelines*. https://www.aiga.org/aiga/content/why-design/design-for-democracy/top-10-election-design-guidelines/
3. Appel, Andrew (December 3, 2018). *Freedom to Tinker: "Why Voters Should Mark Ballots By Hand."* https://freedom-to-tinker.com/2018/12/03/why-voters-should-mark-ballots-by-hand/
4. Appel, Andrew (October 22, 2018). Freedom to Tinker: *"An Unverifiability Principle for Voting Machines."* https://freedom-to-tinker.com/2018/10/22/an-unverifiability-principle-for-voting-machines/
5. Burstein, Chen, Hall/Brennan Center for Justice (2007). *Post-Election Audits: Restoring Trust in Elections*. https://www.brennancenter.org/publication/post-election-audits-restoring-trust-elections
6. DeMillo, Kadel, Marks (2018). *What Voters are Asked to Verify Affects Ballot Verification: A Quantitative Analysis of Voters' Memories of their Ballots*. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3292208
7. ElectionAudits.org (2018). *Principles and Best Practices for Post-Election Tabulation Audits*. https://electionaudits.org/files/Audit Principles and Best Practices 2018.pdf
8. Laskowski, Dawkins, Quesenbery, Frishberg, Smith, Instone/Center for Civic Design (2016). *Principles and Guidelines for Remote Ballot Marking Systems*. https://civicdesign.org/wp-content/uploads/2015/09/Principles-for-remote-ballot-marking-systems-16-0210.pdf
9. Lovato, Jerome/U.S. Election Assistance Commission (2018). *Risk-Limiting Audits: Practical Application*. https://www.eac.gov/assets/1/6/Risk-Limiting_Audits_-_Practical_Application_Jerome_Lovato.pdf
10. National Academies of Sciences, Engineering, and Medicine (2018). *Securing the Vote: Protecting American Democracy*. https://www.nap.edu/catalog/25120/securing-the-vote-protecting-american-democracy
11. National Institute of Standards and Technology, Technical Guidelines Development Committee (2017). Recommendations for *Voluntary Voting System Guidelines 2.0, Principles and Guidelines*. https://www.eac.gov/assets/1/6/TGDC_Recommended_VVSG2.0_P_Gs.pdf
12. National Institute of Standards and Technology (NIST) (2011). *Report of the Auditability Working Group, Approved by the [Technical Guidelines Development Committee] TGDC for Transmittal to the EAC on January 14, 2011*. https://www.eac.gov/assets/1/28/AuditabilityReport_final_January_2011.pdf

13. National Institute of Standards and Technology (2009). NIST IR#7596, *Guidelines for Writing Clear Instructions and Messages for Voters and Poll Workers*. https://ws680.nist.gov/publication/get_pdf.cfm?pub_id=902844

14. National Institute of Standards and Technology (2004). Special Publication 500-256, *Improving the Usability and Accessibility of Voting Systems and Products*. https://www.nist.gov/publications/improving-usability-and-accessibility-voting-systems-and-products

15. Norden, Chen, Kimball, Quesenbery/Brennan Center for Justice (2008). *Better Ballots*. http://www.brennancenter.org/publication/better-ballots

16. State of Georgia Secure, Accessible & Fair Elections (SAFE) Commission (2018). *Request for Information (RFI) for New Voting System*. http://sos.ga.gov/index.php/elections/secure_accessible__fair_elections_safe_commission

17. U.S. Election Assistance Commission, *Voluntary Voting System Guidelines* v. 1.1 (2015). https://www.eac.gov/assets/1/28/VVSG.1.1.VOL.1.FINAL1.pdf

18. U.S. Election Assistance Commission (EAC) (2007). *Effective Designs for the Administration of Federal Elections*. https://www.eac.gov/assets/1/1/EAC_Effective_Election_Design.pdf