# THE MACHINERY OF DEMOCRACY: VOTING SYSTEM SECURITY, ACCESSIBILITY, USABILITY, AND COST

THE BRENNAN CENTER FOR JUSTICE

VOTING TECHNOLOGY ASSESSMENT PROJECT

LAWRENCE NORDEN, PROJECT DIRECTOR

VOTING RIGHTS

& ELECTIONS SERIES

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This paper is the second in a series, which also includes:

*Making the List: Database Matching and Verification Processes for Voter Registration* by Justin Levitt, Wendy Weiser and Ana Muñoz

*The Machinery of Democracy: Protecting Elections in an Electronic World* by the Brennan Center Task Force on Voting System Security

Other resources on voting rights and elections, available on the Brennan Center's website, include:

*Response to the Report of the 2005 Commission on Federal Election Reform* (2005) (co-authored with Professor Spencer Overton)

*Recommendations for Improving Reliability of Direct Recording Electronic Voting Systems* (2004) (co-authored with Leadership Conference on Civil Rights)

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## ABOUT THE VOTING TECHNOLOGY ASSESSMENT PROJECT DIRECTOR

Lawrence Norden is an Associate Counsel with the Brennan Center, working in the areas of voting technology, voting rights, and government accountability. For the past year, Mr. Norden has led the Brennan Center's voting technology assessment project, including the writing and editing of this report. He is a contributor to Routledge's forthcoming *Encyclopedia of American Civil Liberties*. Mr. Norden edits and writes for the Brennan Center's blog on New York State, www.ReformNY.blogspot.com. He is a graduate of the University of Chicago and the NYU School of Law. Mr. Norden serves as an adjunct faculty member in the Lawyering Program at the Benjamin N. Cardozo School of Law. He may be reached at lawrence.norden@nyu.edu.

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# INTRODUCTION

Since the passage of the federal Help America Vote Act ("HAVA") in October of 2002, our nation has been engulfed in a debate over the wisdom of replacing our existing voting machines with new systems that promise fewer ambiguous votes (or, in the case of Florida in 2000, "hanging chads") but also may be vulnerable to attacks or malfunctions. The quest to provide Americans with voting machines that properly record their intended selections and protect those selections in the case of a recount has turned out to be far more difficult than anyone expected. In 2002, many saw electronic voting systems as a panacea: an alternative to punchcard and lever machines that would both record voters' selections more accurately and provide greater accessibility to voters with disabilities. But by 2004, the vulnerability of electronic systems to attack or malfunction spawned a national movement for the return to paper-based systems. Often lost in this public debate about the security of "electronic" versus "paper" systems have been the many other values that elections officials must consider when deciding which systems to purchase and how to best use those systems after they are purchased.

In an effort to address the most serious concerns about new voting technology, the Brennan Center for Justice at NYU School of Law assembled four Task Forces of the nation's leading experts in the areas of security, accessibility, usability and cost, to perform the first ever comprehensive and empirical analysis of electronic voting systems. The analysis focused on the three principal types of voting systems being purchased today: Direct Recording Electronic ("DRE") systems, DREs with voter-verified auditable paper trails ("DREs w/ VVPT"), and Precinct Count Optical Scan ("PCOS") systems. To support Task Force analyses, the Center researched state and local election laws, reviewed voting system contracts, and conducted interviews with hundreds of election officials. The result of this work is a four-chapter report that offers policy makers, election administrators, and members of the public a more nuanced and complete understanding of new voting systems than ever before.

Two themes emerge from our four-part analysis. First, there has been surprisingly little empirical study of voting systems in the areas of security, accessibility, usability, and cost. The result is that jurisdictions are making purchasing decisions and adopting laws and procedures that bear little correlation to the goals they seek to accomplish. Advocates urge security measures that provide questionable security value, while ignoring steps that provide the best chance of catching the simplest attacks on the integrity of an election. Jurisdictions purchase accessible voting machines that do not yet fully address the needs of their disabled communities and without obtaining contractual guarantees that new accessibility features will be added at little or no extra cost as they become available. Counties make decisions about ballot design and instruction language without performing usability testing to avoid voter confusion and mistake. And state and local election officials often purchase voting machines by looking almost exclusively at initial costs, with little regard to long-term costs, which will almost always make up the vast majority of the voting system's *total cost.*

Second, there is not yet any perfect voting system or set of procedures. One system might be more affordable than others, but less accessible to the disabled; some election procedures might make systems easier to use, but less secure. Communities across the country will have to decide what is most important to them: how much are they willing to pay for secure, usable, and accessible systems? Will they sacrifice usability for security? Accessibility for cost? In some cases, the decisions will be mandated by law. In others, there will be difficult choices to make. Election officials and the public should be aware of the trade-offs they are making when choosing one voting system or set of procedures over another, and they should know how to improve achievement of all four values, irrespective of which system they choose.

## VOTING SYSTEMS DEFINED

Although we have analyzed specific manufacturers' products to complete our assessment, our primary objective has not been to rate or rank particular products, but rather to assess the various different *types* of voting systems. Where possible, we have analyzed six voting system architectures.

Direct Recording Electronic ("DRE") voting systems directly record, in electronic form, the voters' selections in each race or contest on the ballot. Typical DRE machines have flat panel display screens with touch-screen input, although other display technologies have been used, including print on paper, and other input technologies have been used, such as push-button. Such systems can be compared with mechanical lever voting machines which directly record votes on mechanical counters inside the machine. Neither DREs nor lever voting machines create a tangible physical record of the voter's selections on a physical ballot.

The defining characteristic of DRE machines is that votes are captured electronically and stored in that form. Such machines may print a durable paper record of the votes cast, for example, after the polls are closed or on an internal printer, but this record is not subject to voter verification. DRE machines also record Event Logs giving the time of each significant operation on the machine, such as when it was set up for an election, when the polls were opened, when the polls were closed, and when a ballot was cast (but not which ballot was cast). At the close of polls, vote totals, the Event Log, and all votes cast may be printed. In addition, electronic records of these may be extracted from the machine (for example, on removable media such as disks or compact electronic memory modules), or the records may be transmitted electronically to a vote collection center (for example, by modem).

Procedures for using these alternatives vary from jurisdiction to jurisdiction. Typically, the electronic transmission or the electronic memory module is delivered to a central vote-counting system (for example, in the county election headquarters), where jurisdiction-wide totals are computed.

There are three subtypes of DRE machines, based on the style of user interfaces/interaction:

1. The scrolling DRE uses a touch-screen to collect user input (when not in an audio ballot mode) and typically allows voters to page through separate screens for separate offices. Examples include: Sequoia Edge, the ES&S iVotronic, Diebold AccuVote-TS and -TSX, AVS WinVote, and UniLect Patriot.

2. The full-face DRE has no paging, and it generally involves an electro-mechanical human interface, which uses switches providing tactile feedback to the voter. (The Avante DRE does produce a full-face ballot that uses a touch-screen) Examples include: Sequoia Advantage, Nedap ESI1 and Danaher/Guardian Voting Systems Shouptronic/ELECTronic 1242.

3. DREs with off-screen mechanical control allow the user to view options displayed on a screen but provides input via buttons, switches, dials or other input devices. Examples include: Hart InterCivic's eSlate.

DREs with Voter-Verifiable Paper Trails ("DRE w/ VVPT") capture voter choices internally in purely electronic form and contemporaneously on paper in a record that can be verified by the voter. The paper record is usually not physically handled by voters, and it remains at the polling place, mechanically stored within or near the DRE machine used to cast the vote. DREs w/ VVPT include those that ensure voter privacy by automatically separating and randomizing vote selections for storage and those with reel-to-reel designs. Proponents of DREs w/ VVPT assume that in the case of a discrepancy between the internally stored electronic vote and the voter-verified physical ballot securely stored within or near the machine, the physical ballots would be the votes of record. Examples include: AccuPoll, Avante Vote-Tracker EVC-308SPR, Sequoia VeriVote with Printer attachment, TruVote, Diebold AccuView VVPT Printer, Diebold Election Systems.

Precinct Count Optical Scan ("PCOS") machines require voters to mark paper ballots, typically with pencils, independent of any machine, and carry their sleeved ballots to un-sleeve and insert into scanners that optically sense their votes. Initial tabulation is generally done at the polling place after the polls close. In most PCOS systems, voters are warned of overvotes and undervotes and are given a chance to correct mistaken ballots. Examples include: Avante Optical Vote Tracker, ES&S Model 100, Sequoia-branded and ES&S-branded Optech III-P Eagle, and Diebold AccuVote-OS.

Ballot Marking Device ("BMD") systems produce a marked ballot (usually paper) that is the result of voter interaction with visual or audio prompts provided by a computerized interface. The result is a voter-verifiable ballot that may or may not be accessibly verified. Some BMDs count votes internally (as do DRE systems)

and may save voter selection information. For any BMD that does count, save, or use cryptography or other techniques to make it difficult to insert fraudulent ballots prepared on other devices (before, during or after actual voting), any discrepancy between records stored within a BMD and physical ballots produced would provide clear evidence of malfunction or fraud and initiate an investigation to determine the source of the discrepancy and the invalid ballots, whether electronic or physical. Examples include: AutoMark and Populex.

Vote-by-Mail systems dispense ballots by mail for voters to mark and mail back to a central location for counting by hand or by machine. Examples include: Hart InterCivic's BallotNow.

Vote-by-Phone systems permit a voter to call a special number, identify herself, and cast a ballot via audio prompts.

Because of a lack of information about the performance of BMD, Vote-by-Mail, and Vote-by-Phone systems, we did not include an assessment of those systems in the chapter on security. Because Vote-by-Mail and Vote-by-Phone are not widely available commercially, we did not include either of these systems in our analysis of the cost of voting systems.

## FINDINGS AND RECOMMENDATIONS

We have included key findings and recommendations in each chapter. These findings and recommendations may be used by state and local governments around the country to make purchasing decisions and to enact laws and procedures that comport with their priorities. Furthermore, policy makers can use these findings and recommendations to ensure that no matter what their priorities are, their voting systems will be as secure, accessible, usable, and affordable as possible. The recommendations from each chapter are listed in brief below.

### CHAPTER ONE: VOTING SYSTEM SECURITY

Three fundamental points emerge from our security analysis: (1) All of the most commonly purchased electronic voting systems – DREs, DREs w/ VVPT, and PCOS – have significant security and reliability vulnerabilities, which pose a real danger to the integrity of national, state, and local elections. (2) The most troubling vulnerabilities of each system can be substantially remedied if proper countermeasures are implemented at the state and local level. (3) Few jurisdictions have implemented any of the key countermeasures that could make the least difficult attacks against voting systems much more difficult to execute successfully.

The Brennan Center's Task Force on Voting System Security reviewed more than 120 potential threats to voting systems. Among its key conclusions was the finding that attacks involving the insertion of software attack programs or other corrupt software are the least difficult attacks against *all* electronic systems currently

being purchased, when the goal is to change the outcome of a close statewide election. In addition, voting machines that have wireless components are significantly more vulnerable to a wide array of attacks. Currently, only two states, New York and Minnesota, ban wireless components on all voting machines.

There are a number of steps that jurisdictions can take to address the vulnerabilities identified in the analysis and make their voting systems significantly more secure. The Task Force recommends adoption of the following security measures:

- Conduct automatic routine audits comparing voter-verified paper records to the electronic record following every election. A voter-verified paper record accompanied by a solid automatic routine audit of those records can go a long way toward making the least difficult attacks much more difficult.

- Perform "parallel testing" (selection of voting machines at random and testing them as realistically as possible) on Election Day. For paperless DREs, in particular, parallel testing will help jurisdictions detect software-based attacks as well as subtle software bugs that may not be discovered during inspection and other testing.

- Ban use of voting machines with wireless components. All three voting systems are more vulnerable to attack if they have wireless components.

- Use a transparent and random selection process for all auditing procedures. For any auditing to be effective (and to ensure that the public is confident in such procedures), jurisdictions must develop and implement transparent and random selection procedures.

- Ensure decentralized programming and voting system administration. Where a single entity, such as a vendor or state or national consultant, performs key tasks for multiple jurisdictions, attacks against statewide elections become easier.

- Institute clear and effective procedures for addressing evidence of fraud or error. Both Automatic Routine Audits and Parallel Testing are of questionable security value without effective procedures for action where evidence of machine malfunction and/or fraud is discovered. Detection of fraud without an appropriate response will not prevent attacks from succeeding.

Fortunately, these steps are not particularly complicated or cumbersome. For the most part, they do not involve significant changes in system architecture. Unfortunately, *very few jurisdictions have implemented any of the security measures that the Task Force's analysis shows are necessary to make voting systems substantially more secure.*

## CHAPTER TWO: VOTING SYSTEM ACCESSIBILITY

There are many reasons for election officials and the general public to be concerned with ensuring that we have created fully accessible voting systems. Not least of these is that the creation of such systems is long overdue: even today, millions of Americans cannot vote independently and secretly on the voting machines in their precincts. For this reason, many of these citizens have found voting to be a difficult and demeaning experience. It should surprise no one that the majority of such citizens do not vote.

In addition to reasons of fundamental fairness, there are practical reasons for election officials to ensure that their systems are accessible. First, it is legally required. Second, disabled voters represent a very large and growing segment of the population. Put plainly, no matter where their jurisdictions are located, election officials are likely to find that a significant percentage of the citizens they work for are disabled and that the numbers of such citizens will continue to grow for the foreseeable future.

To ensure that voting systems are as accessible as possible, the Brennan Center's Task Force on Voting System Accessibility makes the following recommendations:

- Accessibility assessments must take into account the specific needs of citizens with multiple disabilities. For example, solutions that solve barriers faced by voters with visual impairments by providing an audio ballot do not help a voter who is both blind and deaf.

- To determine accessibility, officials and advocates should examine each step a voting system requires a voter to perform, starting with ballot marking and ending with ballot submission. Systems that may provide enhanced accessibility features at one stage of the voting process may be inaccessible to the same voters at another stage in that process.

- Accessibility tests must take into account a full range of disabilities. When selecting participants for system tests, officials and advocates should include people with sensory disabilities (*e.g.*, vision and hearing impairments), people with physical disabilities (*e.g.*, spinal cord injuries and coordination difficulties), and people with cognitive disabilities (*e.g.*, learning disabilities and developmental disabilities). Given the rising number of older voters, officials should take pains to include older voters in their participant sample.

- All accessibility tests should be carried out with full ballots that reflect the complexity of ballots used in elections. A simplified ballot with only a few races or candidates may produce misleading results.

- Many features that ensure accessible voting are new to the market or still in development. As election officials purchase systems today, they should obtain

contractual guarantees from vendors that vendors will retrofit their systems with new accessibility features as such technology becomes available, and that these adjustments will be made at little or no extra cost.

## CHAPTER THREE: VOTING SYSTEM USABILITY

The performance of a voting system is measured in part by its success in allowing a voter to cast a valid ballot that reflects her intended selections without undue delays or burdens. This system quality is known as "usability." Following several high-profile controversies in the last few elections – including, most notoriously, the 2000 controversy over the "butterfly ballot" in Palm Beach – voting system usability is a subject of utmost concern to both voters and election officials. After careful study of published research and new studies conducted for this report on the voter confidence in and effectiveness and efficiency of various electronic voting systems, the Brennan Center's Task Force on Voting System Usability makes the following recommendations:

- Do not assume familiarity with technology. Where feasible, elections officials should address this concern in usability testing among likely voters to determine the precise effects of different design elements upon voters with limited familiarity with the technology in question. The results of such testing should also inform the design of voter education and outreach and poll worker training prior to the election.

- Conduct usability testing on proposed ballots before finalizing their design. Usability testing of specific models within a type of voting system is critical if election officials are to reduce unnecessary voter errors.

- Create plain language instructions and messages in both English and other languages commonly used in the jurisdiction. Use of plain language that is easy to understand quickly is critical to avoiding voter error. Plain language instructions in both English and other prevalent languages are critical to reduce voter errors, even where multiple language ballots are not required under the Voting Rights Act.

- Locate instructions so they are not confusing or ignored. Instructions should be placed in the top left of the frame, where possible. In addition, information should be presented in a single-column format rather than a multi-column format to improve readability.

- For both ballots and instructions, incorporate standard conventions used in product interfaces to communicate a particular type of information or message. Consistent use of generic conventions (*e.g.*, red = warning or error) throughout the voting process allows the voter to rely on her existing experience to streamline the process and clarify otherwise ambiguous instructions.

- Do not create ballots where candidates for the same office appear in multiple columns or on multiple pages. Listing candidates for the same office in multiple columns or on multiple pages (as in the infamous "butterfly ballot" used in Palm Beach County, Florida in 2000, or in optical scan ballots that allow a contest to continue from one column to another) produces higher rates of residual votes (both overvotes and undervotes).

- Use fill-in-the-oval ballots, not connect-the-arrow ballots, for optical scan systems. In optical scan systems, residual votes (and especially overvotes) are less common on fill-in-the-oval ballots than on connect-the-arrow ballots. The latter design should not be used.

- Eliminate extraneous information on ballots. Ballot design should eliminate all extraneous information from the voter's field of vision and minimize visual or audio distractions from the task at hand. Voters may become overwhelmed or confused by unnecessary material.

- Ensure that ballot instructions make clear that voters should not cast both a write-in and normal vote. Write-in lines are a source of many overvotes, as many voters select a candidate whose name is printed on the ballot and then write the same name on the write-in line. Election officials should make sure that instructions clearly state voters should not cast votes in both areas of the ballot. At the same time, state laws should be amended to require that such ballots be counted rather than set aside as spoiled, as long as both the write-in vote and the normal vote are clearly cast for the same candidate.

- Provide mechanisms for recording and reviewing votes. Voting systems should provide ongoing feedback to the voter to ensure that she knows which selections she has already made, and which remain. This information helps to prevent voter confusion, which may otherwise result in lost votes.

- Make clear when the voter has completed each step or task in the voting process. Whether through clear organization of the ballot or through express messages on a screen, the system should reduce the likelihood of confusion or error by instructing voters how to complete each task and then making clear when each task has been successfully completed.

- Minimize the memory load on the voter by allowing her to review, rather than remember, each of her choices during the voting process. Undue memory burdens reduce accuracy and may confuse voters and lead to errors or delays.

- Ensure that the voting system plainly notifies the voter of her errors. In particular, a voter should be informed of any over- or undervote prior to casting her vote. In paper-based systems such as optical scan systems, this require-

ment means that the scanner must be programmed so that the ballot is immediately returned to the voter for correction of either of these kinds of error.

- Make it easy for voters to correct their errors. If voters find it difficult to correct their own errors during the voting process, then the number of voters who choose not to make corrections increases, leading to higher residual vote rates. Accordingly, the mechanism for correcting errors must be easy both to understand and to execute, without any unnecessary, extra steps to complete.

## CHAPTER FOUR: VOTING SYSTEM COST

In interviews with the Brennan Center, election officials frequently cited cost as *the* determinative factor when choosing among systems. All too often, however, they did not have sufficient information to understand the full cost implications of purchasing any particular system.

The Brennan Center surveyed hundreds of election officials, interviewed dozens more, and reviewed over 35 recently completed contracts and bids for voting machines. Based on the results of our surveys, interviews and review of contracts and bids, we reached the following conclusions about voting system cost:

- The total costs of voting systems will vary greatly from jurisdiction to jurisdiction depending on at least seven different factors. These factors, and their likely effects on cost, are detailed in this report.

- The initial costs of a voting system are likely to be a small percentage of the system over its total life-span. Voting systems that initially cost a jurisdiction less money may end up being more expensive than other systems after a few years.

- DRE systems without VVPT are less expensive than similar DREs w/ VVPT under all circumstances, for both initial and ongoing costs.

- PCOS systems (with accessible DREs) are less expensive than similar PCOS systems with BMDs under all circumstances, for both initial and ongoing costs.

- Vendors offer significant volume discounts. To the extent that counties and states can pool their purchases, they are likely to save considerably in the purchase of their voting systems.

# SECURITY

## ABOUT THE TASK FORCE

In 2005, the Brennan Center convened a Task Force of internationally renowned government, academic, and private-sector scientists, voting machine experts and security professionals to conduct the nation's first systematic analysis of security vulnerabilities in the three most commonly purchased electronic voting systems. The Task Force spent more than a year conducting its analysis and drafting this report. During this time, the methodology, analysis, and text were extensively peer reviewed by the National Institute of Standards and Technology ("NIST"). The members of the Task Force are:

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Lawrence D. Norden, Brennan Center for Justice

*Principal Investigator*
Eric L. Lazarus, DecisionSmith

*Experts*
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## ABOUT THE TASK FORCE CHAIR

Lawrence Norden is an Associate Counsel with the Brennan Center, working in the areas of voting technology, voting rights, and government accountability. For the past year, Mr. Norden has led the Brennan Center's voting technology assessment project, including the production and creation of this report. He is a contributor to Routledge's forthcoming *Encyclopedia of American Civil Liberties*. Mr. Norden edits and writes for the Brennan Center's blog on New York State, www.ReformNY.blogspot.com. He is a graduate of the University of Chicago and the NYU School of Law. Mr. Norden serves as an adjunct faculty member in the Lawyering Program at the Benjamin N. Cardozo School of Law. He may be reached at lawrence.norden@nyu.edu.

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Jeremy Creelan, Associate Attorney at Jenner & Block LLP, deserves credit for conceiving, launching. and supervising the Brennan Center's voting technology assessment project, including development of this report, as Deputy Director of the Center's Democracy Program through February 2005. The Program misses him greatly and wishes him well in private practice, where he continues to provide invaluable *pro bono* assistance.

The Brennan Center is grateful to Task Force member Lillie Coney, Associate Director of the Electronic Privacy Information Center. Among many other contributions, she provided invaluable assistance in assembling the Task Force, and frequently offered the Brennan Center sage strategic advice.

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# INTRODUCTION

In these pages, the Brennan Center for Justice at NYU School of Law (the "Brennan Center") summarizes the nation's first systematic analysis of security vulnerabilities in the three most commonly purchased electronic voting systems. To develop the analysis, the Brennan Center convened a Task Force of internationally renowned government, academic, and private-sector scientists, voting machine experts, and security professionals.

The Task Force examined security threats to the *technologies* used in Direct Recording Electronic voting systems ("DREs"), DREs with a voter-verified auditable paper trail ("DREs w/ VVPT") and Precinct Count Optical Scan ("PCOS") systems. The analysis assumes that appropriate physical security and accounting procedures are in place.

FIGURE S1

VOTING SYSTEMS

| Type of Voting System | Description of Voting System | Examples of Voting System |
|---|---|---|
| Direct Recording Electronic (DRE) | A DRE machine directly records the voter's selections in each contest, using a ballot that appears on a display screen. Typical DRE machines have flat panel display screens with touch-screen input, although other display technologies have been used. The defining characteristic of these machines is that votes are captured and stored electronically. | Microvote Infinity Voting Panel<br>Hart InterCivic eSlate<br>Sequoia AVC Edge<br>Sequoia AVC Advantage<br>ES&S iVotronic<br>ES&S iVotronic LS<br>Diebold AccuVote-TS<br>Diebold AccuVote-TSX<br>Unilect Patriot |
| DRE with Voter-Verified Paper Trail (DRE w/ VVPT) | A DRE w/ VVPT captures a voter's choice both internally in electronic form, and contemporaneously on paper. A DRE w/ VVPT allows the voter to confirm the accuracy of the paper record to provide voter-verification. | ES&S iVotronic system with Real Time Audit Log<br>Diebold AccuVote-TSX with AccuView printer<br>Sequoia AVC Edge with VeriVote printer<br>Hart InterCivic eSlate with VVPAT<br>Unilect Patriot with VVPAT |
| Precinct Count Optical Scan (PCOS) | PCOS voting machines allows voters to mark paper ballots, typically with pencils or pens, independent of any machine. Voters then carry their sleeved ballots to a scanner. At the scanner, they un-sleeve the ballot and insert into the scanner, which optically records the vote. | Diebold AccuVote-OS<br>ES&S Model 100<br>Sequoia Optech Insight |

The full report (the "Security Report"), which has been extensively peer reviewed by the National Institute of Standards and Technology ("NIST"), may be found at www.brennancenter.org. Following the analysis outlined here, the Brennan Center and Task Force members recommend countermeasures that should be taken to reduce the technological vulnerability of each voting system.[1]

## CORE FINDINGS

Three fundamental points emerge from the threat analysis in the Security Report:

- All three voting systems have significant security and reliability vulnerabilities, which pose a real danger to the integrity of national, state, and local elections.
- The most troubling vulnerabilities of each system can be substantially remedied if proper countermeasures are implemented at the state and local level.
- Few jurisdictions have implemented any of the key countermeasures that could make the least difficult attacks against voting systems much more difficult to execute successfully.

## VOTING SYSTEM VULNERABILITIES

After a review of more than 120 potential threats to voting systems, the Task Force reached the following crucial conclusions:

For *all three* types of voting systems:

- When the goal is to change the outcome of a close statewide election, attacks that involve the insertion of software attack programs or other corrupt software are the least difficult attacks.
- Voting machines that have wireless components are significantly more vulnerable to a wide array of attacks. Currently, only two states, New York and Minnesota, ban wireless components on all voting machines.

For DREs *without* voter-verified paper trails:

- DREs without voter-verified paper trails do not have available to them a powerful countermeasure to software attacks: post-election automatic routine audits that compare paper records to electronic records.

For DREs w/ VVPT and PCOS:

- The voter-verified paper record, *by itself,* is of questionable security value. The paper record has significant value only if an automatic routine audit is performed (and well designed chain of custody and physical security procedures are followed). Of the 26 states that mandate voter-verified paper records, only 12 require regular audits.

- Even if jurisdictions routinely conduct audits of voter-verified paper records, DREs w/ VVPT and PCOS are vulnerable to certain software attacks or errors. Jurisdictions that conduct audits of paper records should be aware of these potential problems.

## SECURITY RECOMMENDATIONS

There are a number of steps that jurisdictions can take to address the vulnerabilities identified in the Security Report and make their voting systems significantly more secure. We recommend adoption of the following security measures:

1. Conduct automatic routine audits comparing voter-verified paper records to the electronic record following every election. A voter-verified paper record accompanied by a solid automatic routine audit of those records can go a long way toward making the least difficult attacks much more difficult.

2. Perform "parallel testing" (selection of voting machines at random and testing them as realistically as possible on Election Day.) For paperless DREs, in particular, parallel testing will help jurisdictions detect software-based attacks, as well as subtle software bugs that may not be discovered during inspection and other testing.

3. Ban use of voting machines with wireless components. All three voting systems are more vulnerable to attack if they have wireless components.

4. Use a transparent and random selection process for all auditing procedures. For any auditing to be effective (and to ensure that the public is confident in such procedures), jurisdictions must develop and implement transparent and random selection procedures.

5. Ensure decentralized programming and voting system administration. Where a single entity, such as a vendor or state or national consultant, performs key tasks for multiple jurisdictions, attacks against statewide elections become easier.

6. Institute clear and effective procedures for addressing evidence of fraud or error. Both Automatic Routine Audits and Parallel Testing are of questionable security value without effective procedures for action where evidence of machine malfunction and/or fraud is discovered. Detection of fraud without an appropriate response will not prevent attacks from succeeding.

Fortunately, these steps are not particularly complicated or cumbersome. For the most part, they do not involve significant changes in system architecture. Unfortunately, *few jurisdictions have implemented any of these security recommendations.*

Good threat analyses allow us to identify and implement the best security precautions.

# VOTING SYSTEM VULNERABILITIES

## WHAT IS A THREAT ANALYSIS AND WHY IS IT NECESSARY?

In the last several years, few issues in the world of voting systems have garnered as much public attention as voting system security. This attention to voting system security has the potential to be a positive force. Unfortunately, too much of the public discussion surrounding security has been marred by claims and counter-claims that are based on little more than speculation or anecdote.

In response to this uninformed discussion, and with the intention of assisting election officials and the public as they make decisions about their voting machines, the Task Force undertook a methodical analysis of potential threats to voting systems. The threat analysis provides election officials and concerned citizens with *quantifiable* criteria for measuring the level of security offered by voting systems and potential safety measures. It should assist jurisdictions in deciding (a) which voting systems to certify or purchase, and (b) how to protect those systems from security threats after they have been purchased. The Security Report sets forth the detailed results of that analysis, which are summarized here.

### SYSTEMATIC THREAT ANALYSES OF VOTING SYSTEMS ARE LONG OVERDUE.

Most Americans would agree that the integrity of our elections is fundamental to our democracy. We want citizens to have full confidence that their votes will be accurately recorded. Given the current tenor of debate over voting system security, this is reason enough to conduct regular systematic threat analyses of voting systems.

Just as importantly, such analyses, if utilized in developing voting system standards and procedures, should reduce the risk of attacks on voting systems. As a nation, we have not always successfully avoided such attacks – in fact, various types of attacks on voting systems and elections have a "long tradition" in American history.[2] The suspicion or discovery of such attacks has generally provoked momentary outrage, followed by periods of historical amnesia.[3]

All technology, no matter how advanced, is going to be vulnerable to attack to some degree. The history of attacks on voting systems teaches us how foolish it would be to assume that there will not be attacks on voting systems in the future. But we can educate ourselves about the vulnerabilities and take the proper precautions to ensure that the easiest attacks, with the potential to affect the most votes, are made as difficult as possible. Good threat analyses allow us to identify and implement the best security precautions.

## SOLID THREAT ANALYSES SHOULD HELP MAKE SYSTEMS MORE RELIABLE.

There is an additional benefit to this kind of analysis: it should help make our voting systems more reliable, *regardless of whether they are ever attacked.* Computerized voting systems – like all previous voting systems – have shown themselves vulnerable to error. As detailed in the Security Report, votes have been miscounted or lost as a result of defective firmware (coded instructions in a computer system's hardware), faulty machine software, defective tally server software, election programming errors, machine breakdowns, malfunctioning input devices, and pollworker error.

Almost everything that a malicious attacker could attempt could also happen by accident.

"An old maxim in the area of computer security is clearly applicable here: Almost everything that a malicious attacker could attempt could also happen by accident; for every malicious attacker, there may be thousands of people making ordinary careless errors."[4] Solid threat analyses should help to expose and to address vulnerabilities in voting systems, including not only security breaches but also simple malfunctions.

## WHAT METHODOLOGY WAS USED FOR THE THREAT ANALYSIS?

In developing the study of voting system security vulnerabilities, the Brennan Center brought together some of the nation's leading election officials, as well as a Task Force of internationally recognized experts in the fields of computer science, election policy, security, voting systems, and statistics. After considering several approaches to measuring the strength of election security, this group unanimously selected a model that: (a) identified and categorized the potential threats against voting systems, (b) prioritized these threats based upon an agreed-upon metric (which would identify how "difficult" each threat is to accomplish from the attacker's point of view), and (c) determined (utilizing the same metric employed to prioritize threats) how much more difficult each of the catalogued attacks would become after various sets of countermeasures were implemented.

After several months of work, including a public threat analysis workshop hosted by the National Institute of Standards and Technology, the Task Force identified and categorized more than 120 threats to the three voting systems. The threats generally fell into one or more of nine broad categories: (1) the insertion of corrupt software into machines prior to Election Day; (2) wireless and other remote attacks on voting machines on Election Day; (3) attacks on tally servers; (4) miscalibration of voting machines; (5) shut-off of voting machine features intended to assist voters; (6) denial of service attacks; (7) actions by corrupt poll workers or others at the polling place to affect votes cast; (8) vote buying schemes; and (9) attacks on ballots or voter-verified paper trails.

The Task Force determined that the best single metric for determining the "dif-

ficulty" of each of these attacks was the number of informed participants necessary to execute the attack successfully. An "informed participant" is someone whose participation is needed to make the attack work, and who knows enough about the attack to foil or expose it.

For each attack, Task Force members looked at how many informed participants would be necessary to change the outcome of a reasonably close statewide election in which all votes were cast on one of the three voting systems analyzed. The statewide election we looked at was a fictional gubernatorial race between Tom Jefferson and Johnny Adams in a composite jurisdiction, Pennasota. Pennasota was created by aggregating the results of the 2004 presidential election in 10 "battleground" states, as determined by Zogby International polls in the spring, summer, and fall of 2004.

FIGURE S2

ELECTION FOR GOVERNOR, STATE OF PENNASOTA, 2007

| Candidate | Party | Total Votes | Percentage of Votes |
|---|---|---|---|
| Tom Jefferson | Dem-Rep | 1,769,818 | 51.1 |
| Johnny Adams | Federalists | 1,689,650 | 48.8 |

To figure out how many informed participants would be needed to change the outcome of this election, and make Johnny Adams the next Governor of Pennasota, the experts broke down each attack into its necessary parts, assigned a value representing the minimum number of persons they believed would be necessary to accomplish each part, and then determined how many times the attack would need to be repeated to reverse the election results.

At the conclusion of this process, election officials were interviewed to determine whether they agreed with the assigned steps and values. When necessary, the steps and values were modified to reflect feedback from the officials.

After the attacks were prioritized by level of difficulty, Task Force members reviewed how much more difficult each attack would become if various sets of countermeasures were implemented. The process for determining the difficulty of overcoming countermeasures was exactly the same as the process for determining attack difficulty: each step necessary to overcome the countermeasure was identified and given a value equal to the number of persons necessary to accomplish that step. Election officials were again consulted to confirm that the steps and values assigned were reasonable.

To ensure that the results of our analysis were robust and not limited to the composite jurisdiction of Pennasota, we ran our threat analysis against the actual results of the 2004 presidential election in Florida, New Mexico, and Pennsylvania. All of the results and findings discussed in this summary applied to our analyses of these three states.

The full work of the Task Force, including the choice of methodology, analysis and report, were extensively peer reviewed by NIST.

Significantly, the threat analysis suggests that all three voting systems are equally vulnerable to software attacks.

## WHAT WERE THE GREATEST RISKS REVEALED BY THE THREAT ANALYSIS?

Below is a discussion of the most troubling threats identified in the Security Report.

### THE LEAST DIFFICULT ATTACKS USE SOFTWARE ATTACK PROGRAMS.

The "least difficult" attacks against all three systems (as measured by the metric of number of informed participants necessary to change the outcome of a statewide election) involve the insertion of corrupt software or other software attack programs in order to take over a voting machine. Significantly, the threat analysis suggests that all three voting systems are equally vulnerable to software attacks.

The most basic type of software attack program would target voting machines and switch a certain number of votes from one candidate to another. This alteration of votes could occur at any time on Election Day, as long as it was completed before poll workers printed a paper record of the vote total and extracted the electronic record of votes from the machines.

Inserting a software attack program into a voting system for the purpose of affecting an election's outcome is likely to be technically and financially challenging, particularly if the attacker wants to avoid detection. However, a substantial historical record of this type of attack against non-voting systems suggests that it can be successfully executed. The Security Report details several ways that an attacker could insert a software attack program without detection.

*Firmware is software that is embedded in the voting machine.*

Specifically, there are several points in the development and use of voting machine software where software attack programs could be inserted without detection. Among these points, software attack programs could be inserted through the "firmware" that is hard-wired into voting machines, during the generation of "commercial off-the-shelf" ("COTS") or vendor software used on voting machines, through software patches and updates meant to improve the performance and capabilities of voting machines, during the creation of configuration files and election definitions used to interpret voter choice and totals on voting machines, through network communications between voting machines and outside sources, as well as through "input/output" devices such as memory cards and printers.

There are many hurdles an attacker would have to overcome to ensure that the insertion of such an attack program changed enough votes to affect the outcome

of a statewide election and escaped detection. After careful analysis, the Task Force determined that none of these hurdles is insurmountable. The full Security Report discusses in detail how an attacker could prevail over the following challenges: efforts of vendors to prevent such an attack from occurring (pp. 32–33); gaining sufficient technical knowledge about the way a voting machine and its software works (pp. 36–37); gaining sufficient knowledge about the targeted election (pp. 37–38); creating an attack program that has the ability to change, add, or subtract votes (pp. 39–40); eluding independent testing authority ("ITA") inspections (pp. 42–45); avoiding detection during machine testing (pp. 44–45); and avoiding detection through records kept on event and audit logs (pp. 45–46).

### WIRELESS COMPONENTS CREATE UNNECESSARY RISKS.

The threat analysis shows that machines with wireless components are particularly vulnerable to software attack programs and other attacks. The Security Report concludes that this danger applies to all three voting systems examined.

*A "Trojan horse" is a type of software attack program that "impersonates" a benign program.*

Vendors continue to manufacture and sell machines with wireless components. Among the many types of attacks made possible by wireless components are attacks that exploit an unplanned vulnerability in the software or hardware to get a Trojan horse into the machine. For this type of attack, a Trojan horse would not have to be inserted in advance of Election Day. Instead, an attacker aware of a vulnerability in the voting system's software or firmware could simply show up at the polling station and beam her Trojan horse into the machine using a wireless enabled personal digital assistant.

*Personal digital assistants ("PDAs" or palmtops) are handheld devices that were originally designed as personal organizers. PDAs can synchronize data with a personal computer.*

Thus, virtually any member of the public with some knowledge of software and a personal digital assistant could perform this attack. This is particularly troubling when one considers that most voting machines run on COTS software and/or operating systems; the vulnerabilities of such software and systems are frequently well known.[5] Against all three systems, attackers could use wireless components to subvert *all* testing. Specifically, an attack program could be written to remain dormant until it received particular commands via a wireless communication. This would allow attackers to wait until a machine was being used to record votes on Election Day before turning on the software attack.

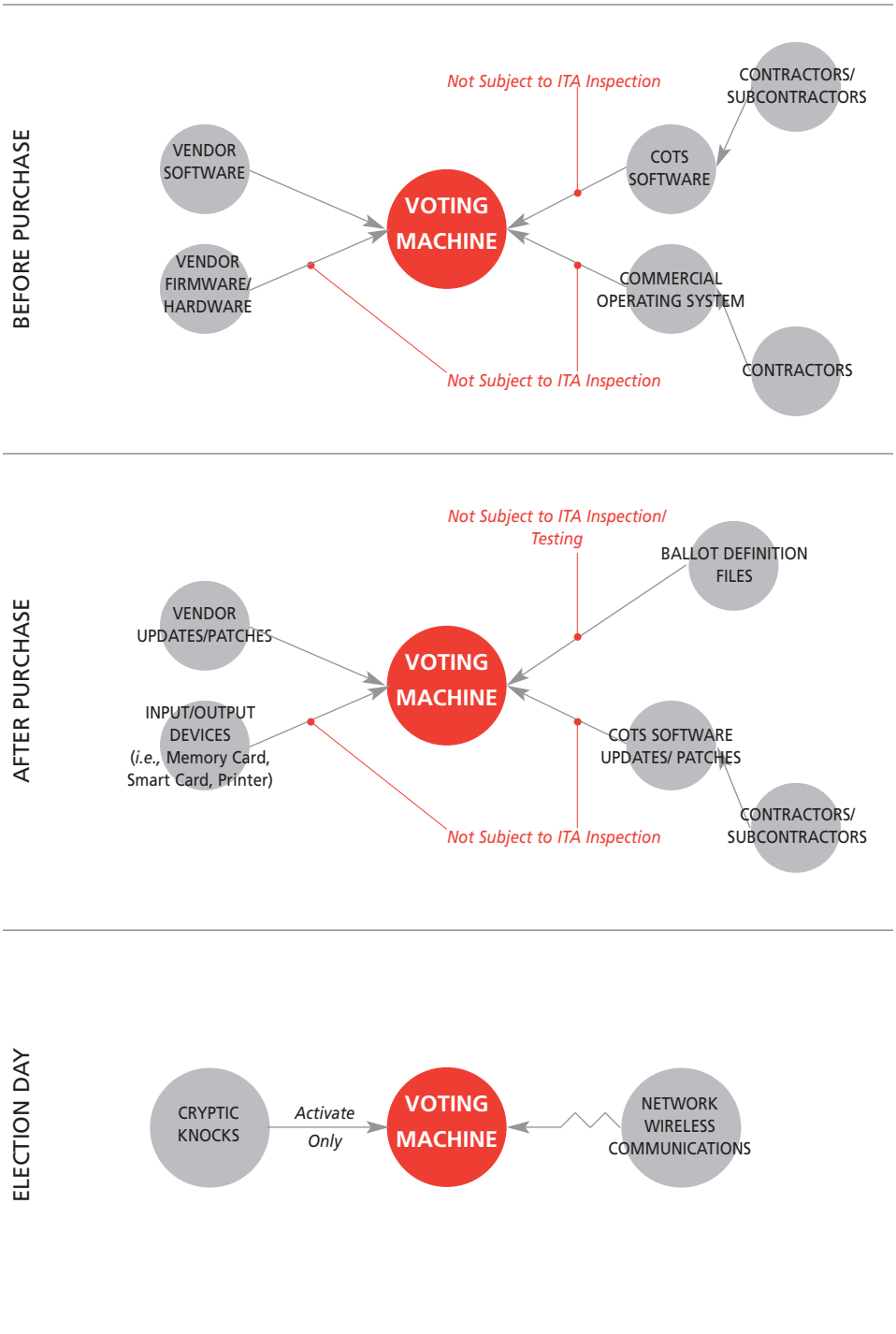
Attackers could also use wireless communications to gain fine-grained control over an attack program already inserted into a particular set of machines (*i.e.*, switch three votes in the second race on the third machine), or obtain information as to how individuals had voted by communicating with a machine while it was being used.

Finally, wireless networking presents additional security vulnerabilities for jurisdictions using DREs w/ VVPT and PCOS. A major logistical problem for an attacker changing both electronic and paper records is how to get the new paper records printed in time to substitute them for the old record in transit. With wire-

less networking, the DRE or PCOS can transmit specific information out to the attacker about what should appear on those printed records. In short, permitting wireless components on DRE w/ VVPT or PCOS machines makes the attacker's job much simpler in practice.

FIGURE S3

SOFTWARE ATTACK PROGRAM: POINTS OF ENTRY




*A cryptic knock is an action taken by a user of the machine that will trigger (or silence) the attack behavior. The cryptic knock could come in many forms, depending upon the attack program: voting for a write-in candidate, tapping a specific spot on the machine's screen, a communication via wireless network, etc.*

Systems with voter-verified paper records provide little, if any, security benefit over systems without such records, unless there are regular audits and/or recounts of the paper records.

## SYSTEMS WITH PAPER RECORDS ARE STILL SUBJECT TO ATTACK.

Voting systems with some kind of voter-verified paper record (*i.e.*, DRE w/VVPT or PCOS) offer an important security advantage against software attack programs not offered by voting systems without voter-verified paper records (*i.e.*, DREs *without* VVPT): jurisdictions can conduct an audit of the voter-verified paper record and compare that record to the electronic vote totals.

Unfortunately, most states that require voter-verified paper records do not require automatic audits of paper records after each election. *Our analysis shows that systems with voter-verified paper records provide little, if any, security benefit over systems without such records, unless there are regular audits and/or recounts of the paper records.*

Even assuming that such regular audits and/or recounts are conducted, jurisdictions that use, or are considering purchasing DREs w/ VVPT or PCOS should be aware of threats that are unique to these systems.

### ATTACKS ON DRE w/VVPT

At least one study has suggested that an extremely low percentage of voters who use DREs w/ VVPT review the paper trail.[6]

If those findings are correct, an attacker could subvert a recount or audit by creating an attack program that directs the machine to record the wrong vote on *both* the electronic and paper records. If both records are similarly inaccurate, checking one against the other in an audit or recount will not expose an attack.

In practice, this is how it would work in the Governor's race in Pennasota:

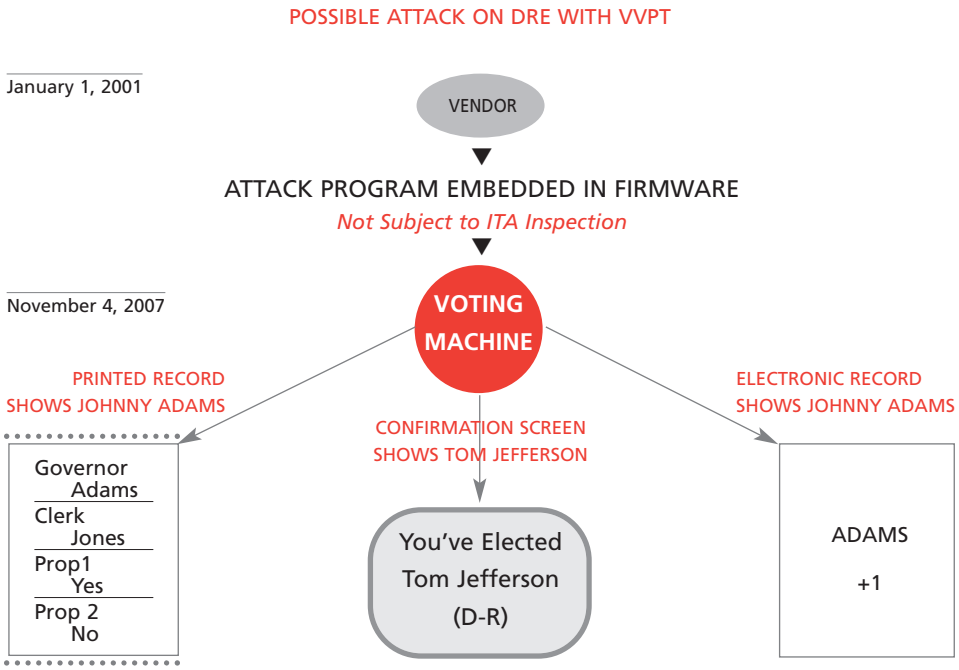
- When a targeted voter chooses Tom Jefferson, the screen would indicate that she has voted for Tom Jefferson.
- After she has completed voting in all other races, the DRE would print a paper record that lists her choices for every race, except for governor. Under the governor's race, it would state that she has selected Johnny Adams.
- When the DRE screen asks the voter to confirm that the paper has recorded her vote correctly, one of two things would happen:
  - the voter would fail to notice that the paper has misrecorded the vote and accept the paper recording; or
  - the voter would reject the paper record and opt to vote again.
- If the voter rejects the paper record, the second time around it would show that she voted for Tom Jefferson. This might lead her to believe she had acci-

dentally pressed the wrong candidate the first time. In any event, it would render her less likely to tell anyone that the machine made a mistake.

Encouraging voters to review the paper records could also substantially reduce the risk of a successful attack on the paper trail.

We can imagine the attack visually this way:

FIGURE S4




This attack would not require any additional participants in the conspiracy. Nor, as demonstrated in the Security Report, is it entirely clear that enough voters would notice the misrecorded votes to prevent the attack from working.

The Security Report details countermeasures that should allow jurisdictions to catch this attack. Specifically, even if only a small percentage of voters notice that a machine has misrecorded their vote, there should be an unusually large number of "cancellations" on the paper trail. A jurisdiction that recorded and then reviewed the number of cancellations during a 2% audit would find enough evidence of problems to identify a problem and understand that further investigation was warranted.

Of course, encouraging voters to review the paper records could also substantially reduce the risk of a successful attack on the paper trail.

## ATTACKS ON PCOS

One of the benefits of PCOS machines over Central Count Optical Scanners (which are very often used in tallying absentee ballots) is that they have an "over/undervote protection." The over/undervote protection on PCOS scan-

ners works as follows: when a voter fills out his ballot, but accidentally fills in two candidates for the same race (overvotes) or accidentally skips a race (undervotes), the scanner would refuse to record the vote and send it back to the voter for examination. The voter then has the opportunity to review the ballot and correct it before resubmitting.

Central Count Optical Scanners have been shown to lose far more votes than PCOS. In precincts with over 30% African American voters, for example, the lost or "residual" vote rate for Central Count Optical Scanners has been shown to be as high as 4.1% as compared with 0.9% for PCOS.[7]

The lack of over/undervote protection on Central Count Optical Scanners may be the reason for this difference.

Our attacker in Pennasota would probably *not* be able to swing the gubernatorial race from Jefferson to Adams merely by inserting an attack program that would turn off the over/undervote protection on PCOS scanners. Even if we assume that the result of turning off the protection were a loss of 4% of the votes on every scanner, and that all of those votes would have gone to Tom Jefferson, this would result in the loss of only about 20,000 votes. This would still leave Jefferson (who won by about 80,000 votes) with a comfortable (though slimmer) margin of victory.

Nevertheless, this attack could cause the loss of thousands of votes. There are at least three possible ways to catch this attack:

- Parallel Testing (assuming that the attack program has not also figured out a way to shut off when it is being tested);
- Periodic testing of the over/undervote protection on Election Day;
- Counting over/undervotes during an audit of the voter-verified paper record to determine whether there is a disproportionate number of such lost votes.

## SECURITY RECOMMENDATIONS

There is a substantial likelihood that the election procedures and countermeasures currently in place in the vast majority of states would not detect a cleverly designed software attack program. The regimens for parallel testing and automatic routine audits proposed in the Security Report are important tools for defending voting systems from many types of attack, including software attack programs.

Most jurisdictions have not implemented these security measures. Of the 26 states that require a voter-verified paper record, only 12 states require automatic audits of those records after every election, and only two of these states – California and Washington – conduct parallel testing.[8]

Moreover, even those states that have implemented these countermeasures have not developed the best practices and protocols that are necessary to ensure their effectiveness in preventing or revealing attacks or failures in the voting systems.

Encouraging voters to review the paper records could also substantially reduce the risk of a successful attack on the paper trail.

### RECOMMENDATION #1:
### CONDUCT AUTOMATIC ROUTINE AUDIT OF PAPER RECORDS.

Advocates for voter-verified paper records have been extremely successful in state legislatures across the country. Currently, 26 states require their voting systems to produce a voter-verified record, but 14 of these states do not require automatic routine audits.[9] The Task force has concluded that an independent voter-verified paper trail without an automatic routine audit is of questionable security value.[10]

By contrast, a voter-verified paper record accompanied by a solid automatic routine audit can go a long way toward making the least difficult attacks much more difficult. Specifically, the measures recommended below should force an attacker to involve hundreds of more informed participants in her attack.

- A small percentage of all voting machines and their voter-verified paper records should be audited.
- Machines to be audited should be selected in a random and transparent way.
- The assignment of auditors to voting machines should occur immediately before the audits. The audits should take place by 9 a.m., the day after polls close.
- The audit should include a tally of spoiled ballots (in the case of VVPT cancellations), overvotes, and undervotes.

- A statistical examination of anomalies, such as higher than expected cancellations or undervotes and overvotes, should be conducted.

- Solid practices with respect to chain of custody and physical security of paper records prior to the automatic routine audit should be followed.

RECOMMENDATION #2:

## CONDUCT PARALLEL TESTING.

It is not possible to conduct an audit of paper records of DREs without VVPT, because no voter-verified paper record exists on such machines. This means that jurisdictions that use DREs without VVPT do not have access to an important and powerful countermeasure.

*Typically, a ballot-marking device is an accessible computer-based voting system that produces a marked ballot. The ballot is marked as the result of voter interaction with visual or audio prompts. Some jurisdictions use ballot-marking devices instead of accessible DREs.*

For paperless DRE voting machines, parallel testing is probably the best way to detect most software-based attacks, as well as subtle software bugs that may not be discovered during inspection and other testing. For DREs w/ VVPT and ballot-marking devices, parallel testing provides the opportunity to discover a specific kind of attack (for instance, printing the wrong choice on the voter-verified paper record) that may not be detected by simply reviewing the paper record after the election is over. However, even under the best of circumstances, parallel testing is an imperfect security measure. The testing creates an "arms-race" between the testers and the attacker, but the race is one in which the testers can never be certain that they have prevailed.

We have concluded that the following steps will lead to more effective parallel testing:

- The precise techniques used for parallel testing (*e.g.*, exactly how and when the machine is activated, how activation codes/smart cards/*etc.* are produced to allow voting, *etc.*) should not be fully determined or revealed until right before the election. Details of how parallel testing is done should change from election to election.

- At least two of each type of DRE (meaning both vendor and model) should be selected for parallel testing.

- At least two DREs from each of the three largest counties should be parallel tested.

- Localities should be notified as late as possible that machines from their precincts will be selected for parallel testing.

- Wireless channels for voting machines should be closed off, to ensure they cannot receive commands.

- Voting machines should never be connected to one another during voting. Some DREs and DREs w/VVPT may be designed so that they cannot function unless they are connected to one another. Election officials should discuss this question with voting system vendors.

- Voting machines should be completely isolated during the election, and print out or otherwise display their totals before being connected to any central server to send in its tallies.

- Parallel testing scripts should include details, such as how quickly or slowly to vote, when to make "errors," and perhaps even when to cast each vote.

- Parallel testing should be videotaped to ensure that a contradiction between paper and electronic records when parallel testing is complete is not the result of tester error.

While a few local jurisdictions have taken it upon themselves to conduct limited parallel testing, we are aware of only three states, California, Maryland and Washington, that have regularly performed parallel testing on a statewide basis. It is worth noting that two of these states, California and Washington, employ automatic routine audits *and* parallel testing as statewide countermeasures against potential attack.

Machines with wireless components are particularly vulnerable to attack.

RECOMMENDATION #3:

## BAN WIRELESS COMPONENTS ON ALL VOTING MACHINES.

Our analysis shows that machines with wireless components are particularly vulnerable to attack. We conclude that this vulnerability applies to all three voting systems. Only two states, New York and Minnesota, ban wireless components on all machines.[11] California also bans wireless components, but only for DRE machines. Wireless components should not be permitted on any voting machine.

RECOMMENDATION #4:

## MANDATE TRANSPARENT AND RANDOM SELECTION PROCEDURES.

The development of transparently random selection procedures for all auditing procedures is key to audit effectiveness. This includes the selection of machines to be parallel tested or audited, as well as the assignment of auditors themselves. The use of a transparent and random selection process allows the public to know that the auditing method was fair and substantially likely to catch fraud or mistakes in the vote totals. In our interviews with election officials we found that, all too often, the process for picking machines and auditors was neither transparent nor random.

Where a single entity, such as a vendor or state or national consultant, runs elections or performs key tasks for multiple jurisdictions, attacks against statewide elections become easier.

In a transparent random selection process:

- The whole process is publicly observable or videotaped.
- The random selection is be publicly verifiable, *i.e.*, anyone observing is able to verify that the sample was chosen randomly (or at least that the number selected is not under the control of any small number of people).
- The process is simple and practical within the context of current election practice so as to avoid imposing unnecessary burden on election officials.

RECOMMENDATION #5:

## ENSURE DECENTRALIZED PROGRAMMING AND VOTING SYSTEM ADMINISTRATION.

Where a single entity, such as a vendor or state or national consultant, runs elections or performs key tasks (such as producing ballot definition files) for multiple jurisdictions, attacks against statewide elections become easier. Unnecessary centralized control provides many opportunities to implement attacks at multiple locations.

RECOMMENDATION #6:

## IMPLEMENT EFFECTIVE PROCEDURES FOR ADDRESSING EVIDENCE OF FRAUD OR ERROR.

Both automatic routine audits and parallel testing are of questionable security value without effective procedures for action where evidence of machine malfunction and/or fraud is uncovered. Detection of fraud without an appropriate response will not prevent attacks from succeeding. In the Brennan Center's extensive review of state election laws and practices, and in its interviews with election officials for the threat analysis, we did not find any jurisdiction with publicly detailed, adequate, and practical procedures for dealing with evidence of fraud or error discovered during an audit, recount, or parallel testing.

The following are examples of procedures that would allow jurisdictions to respond effectively to detection of bugs or software attack programs in parallel testing:

- Impound and conduct a transparent forensic examination of all machines showing unexplained discrepancies during parallel testing.
- Where evidence of a software bug or attack program is subsequently found (or no credible explanation for the discrepancy is discovered), conduct a forensic examination of all DREs used in the state during the election.[12]

- Identify the machines that show evidence of tampering or a software flaw that could have affected the electronic tally of votes.

- Review the reported margin of victory in each potentially affected race. Based upon the (a) margin of victory, (b) number of machines affected, and (c) nature and scope of the tampering or flaw, determine whether there is a substantial likelihood that the tampering or flaw changed the outcome of a particular race.

- Where there is a substantial likelihood that tampering changed the outcome of a particular race, hold a new election for the office.

The following is an illustrative set of procedures that would allow jurisdictions to respond effectively to discrepancies between paper and electronic records during an automatic routine audit:

- Conduct a transparent investigation of all machines where the paper and electronic records do not match to determine whether there is any evidence that tampering with the paper records has occurred.

- To the extent that there is no record that the paper records have been tampered with, certify the paper records.

- If there is evidence that the paper records have been tampered with, give a presumption of authority to the electronic records.

- After giving a presumption of authority to the electronic records, conduct a forensic investigation on all machines where the paper and electronic records do not match, to determine whether there has been any tampering with the electronic records.

- If tampering with the electronic records can be ruled out, certify the electronic records.[13]

- Where there is evidence that both sets of records have been tampered with, conduct a full recount to determine whether and to what extent paper and electronic records cannot be reconciled.

- At the conclusion of the full recount, determine the total number of machines that report different electronic and paper records.

- After quantifying the number of machines that have been tampered with, determine the margin of victory in each potentially affected race.

- Based upon (a) the margin of victory, (b) the number of machines affected,

and (c) the nature and scope of the tampering, determine whether there is a substantial likelihood that tampering changed the outcome of a particular race.

- In the event that a determination is made that there is a substantial likelihood that tampering changed the outcome of a particular race, hold a new election for the office.

## CONCLUSION

The Task Force has found that the three voting systems most commonly purchased today are vulnerable to attacks and errors that could change the outcome of statewide elections. This finding should surprise no one. A review of the history of both election fraud and voting systems literature in the United States shows that voting systems have always been vulnerable to attack. Indeed, it is impossible to imagine a voting system that could be impervious to attack.

But there are straightforward countermeasures that that will substantially reduce the most serious security risks presented by the three systems.

The Task Force's recommendations point the way for jurisdictions with the political will to protect their voting systems from attack. None of the measures identified here – auditing voter-verified paper records, banning wireless components, using transparent and random selection processes for auditing, adopting effective policies for addressing evidence of fraud or error in vote totals, conducting parallel testing – are particularly difficult or expensive to implement.[14] The Brennan Center urges election officials and policy makers to adopt the recommended security measures as soon as possible.

# ENDNOTES

[1] NIST has informed the Brennan Center that the development of policy recommendations for voting systems is not within the agency's mission or institutional authority. Accordingly, the policy recommendations in the report should not be attributed to Task Force members who work for NIST.

[2] Tracy Campbell, DELIVER THE VOTE, at xvi (2005) (pointing to, among other things, a history of vote buying, ballot stuffing, and transposing of results).

[3] *Id.*

[4] Douglas W. Jones, *Threats to Voting Systems,* NIST Threat Analysis Workshop Presentation (Oct. 7, 2005), *available at* http://vote.nist.gov/threats/papers/threats_to_voting_systems.pdf (last visited May 25, 2006).

[5] *See, e.g.*, Brian Krebs, *Windows Security Flaw is 'Severe,'* Washington Post, Dec. 30, 2005, at D1 (publicizing a previously unknown flaw in Microsoft Windows).

[6] Ted Selker and Sharon Cohen, *An Active Approach to Voting Verification,* CalTech/MIT Voting Technology Project, Working Paper #28 (May 2005), *available at* http://vote.caltech.edu/media/documents/wps/vtp_wp28.pdf (last visited May 25, 2006).

[7] *See Voting System Usability, infra* p. 89 (original research by Prof. David Kimball).

[8] Maryland, which does not have a voter-verified paper record requirement, also conducts parallel testing statewide. The 12 states that must conduct automatic audits of voter-verified paper records are: AK, CA, CO, CT, HI, IL, MN, NM, NC, NY, WA, and WV.

[9] The 26 states are: AK, CA, CO, CT, HI, ID, IL, ME, MI, MN, MO, MT, NC, NH, NJ, NM, NV, NY, OH, OR, SD, UT, VT, WA, WI, and WV.

[10] Laws providing for inexpensive candidate-initiated recounts might also add security for voter-verified paper. The Task Force did not examine such recounts as a potential countermeasure.

[11] Two other states, West Virginia and Maine, ban networking of machines without banning wireless components themselves. Banning the *use* of wireless components (even when that involves disabling them), rather than requiring *removal* of these components, still leaves voting systems unnecessarily insecure. Among other reasons, a software attack program could be designed to re-activate any disabling of the wireless component.

[12] *See* RECOMMENDATIONS OF THE BRENNAN CENTER FOR JUSTICE AND THE LEADERSHIP CONFERENCE ON CIVIL RIGHTS FOR IMPROVING RELIABILITY OF DIRECT RECORDING ELECTRONIC VOTING SYSTEMS (2004), *available at* http://www.brennancenter.org/programs/downloads/voting_systems_final_ recommendations.pdf (last visited May 25, 2006) (recommending that jurisdictions hire independent security experts and create independent security oversight panels to implement and oversee security measures). Independent security experts and oversight panel members should be present during any forensic investigation, to increase its transparency.

[13] When a state determines that electronic records should be given a presumption of authority, the reverse process should be followed: first investigate the electronic records for tampering, then (if necessary) examine the paper records.

[14] Even routine parallel testing and audits of voter-verified paper records – perhaps the most costly and time-consuming countermeasures reviewed in the joint threat analysis – have been shown to be quite inexpensive. Jocelyn Whitney, Developer and Project Manager for parallel testing activities in the State of California, provided the Brennan Center with data showing that the total cost of parallel testing in California was approximately *12 cents per vote* cast on DREs. E-mail from Jocelyn Whitney to Lawrence Norden, Associate Counsel, Brennan Center for Justice

(February 25, 2006) (on file with the Brennan Center). Harvard L. Lomax, Registrar of Voters for Clark County, Nevada, estimates that a team of auditors can review 60 votes on a voter verified paper trail in four hours. Assuming that auditors are paid $12 per hour and that each team has two auditors, the cost of such audits should be little more than *3 cents per vote*, if 2% of all votes are audited. Telephone Interview by Eric L. Lazarus and Lawrence Norden with Harvard L. Lomax (March 23, 2006). Each of these costs represents a tiny fraction of what jurisdictions already spend annually on elections. The Brennan Center's study of voting system costs shows that, for instance, most jurisdictions spend far more than this on printing ballots (as much as $0.92 per ballot), programming machines (frequently more than $0.30 per vote per election), or storing and transporting voting systems. Lawrence Norden, *Voting System Cost, infra* p. 123.

# ACCESSIBILITY

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## INTRODUCTION

Traditionally, many voters with disabilities have been unable to cast their ballots without assistance from personal aides or poll workers. Those voters do not possess the range of visual, motor, and cognitive facilities typically required to operate common voting systems. For example, some are not be able to hold a pen or stylus to mark a ballot that they must see and read. Thus, the voting experience for citizens who cannot perform certain tasks – reading a ballot, holding a pointer or pencil – has not been equal to that of their peers without disabilities.

The Help America Vote Act of 2002 took a step forward in addressing this long-standing inequity. According to HAVA, new voting systems must allow voters with disabilities to complete and cast their ballots "in a manner that provides the same opportunity for access and participation (including privacy and independence) as for other voters."[1] In other words, as jurisdictions purchase new technologies designed to facilitate voting in a range of areas, they must ensure that new systems provide people with disabilities with an experience that mirrors the experience of other voters.

This report is designed to help state and local jurisdictions improve the accessibility of their voting systems. We have not conducted any direct accessibility testing of existent technologies. Rather, we set forth a set of critical questions for election officials and voters to use when assessing available voting systems, indicate whether vendors have provided any standard or custom features designed to answer these accessibility concerns, and offer an evaluation of each architecture's limitations in providing an accessible voting experience to all voters.

The report thus provides a foundation of knowledge from which election officials can begin to assess a voting system's accessibility. The conclusions of this report are not presented as a substitute for the evaluation and testing of a specific manufacturer's voting system to determine how accessible a system is in conjunction with a particular jurisdiction's election procedures and system configuration. We urge election officials to include usability and accessibility testing in their product evaluation process.

# THE NEED FOR ACCESSIBLE VOTING SYSTEMS

There are many reasons for election officials to be concerned about creating fully accessible voting systems. Not least of these is that such systems are long overdue: even today, millions of Americans cannot vote independently on secret ballots using the voting machines in their precincts.[2] For this reason, many of these citizens have found voting to be an "embarrassing, demeaning and time consuming" experience.[3] It should surprise no one that the majority of such citizens do not vote.[4]

In addition to reasons of fundamental fairness, there are practical reasons for election officials to ensure that their systems are accessible. First, it is legally required. Second, disabled voters represent a very large and growing segment of the population. Put plainly, no matter where their jurisdictions are located, election officials are likely to find that a significant percentage of the citizens they serve are disabled, and the numbers of such citizens will continue to grow for the foreseeable future.

## LEGAL ACCESSIBILITY REQUIREMENTS FOR VOTING SYSTEMS

Current accessibility standards reflect evolving standards in federal legislation and an essentially private certification regime formerly led by the National Association of State Election Directors ("NASED") and now overseen by the Election Assistance Commission ("EAC").[5] This section summarizes those requirements and their role in state selection decisions.

### The Help America Vote Act

Congress has only recently passed an explicit law requiring a private and independent voting experience for people with disabilities. Under the federal Help America Vote Act ("HAVA"), at least one voting system "equipped for individuals with disabilities" must be used at each polling place for federal elections held on or after January 1, 2006.[6] HAVA requires that such voting systems:

> be accessible for individuals with disabilities, including non-visual accessibility for the blind and visually-impaired, in a manner that provides the same opportunity for access and participation (including privacy and independence) as for other voters.[7]

Specifically, every polling place shall have "at least one direct recording electronic voting system or other voting system equipped for individuals with disabilities."[8] In addition, all voting systems "purchased with funds made available under [HAVA] on or after January 1, 2007" must meet the statute's standard for disability access.[9] HAVA also requires that the voting system provide alternative language accessibility as already required by section 203 of the Voting Rights Act.[10]

### The Americans with Disabilities Act and the Rehabilitation Act

While HAVA is the first Congressional statute explicitly to require a private and independent voting experience for people with disabilities, earlier statutes cemented a strong foundation for equal access to the polls for voters with disabilities. The Americans with Disabilities Act of 1990 ("ADA") and the Rehabilitation Act of 1973 prohibit exclusion of the disabled from government services, programs, or activities, including voting and elections. Title II of the ADA provides that "no qualified individual with a disability shall, by reason of such disability, be excluded from participation in or be denied the benefits of the services, programs, or activities of a public entity, or be subjected to discrimination by any such entity."[11] Similarly, Section 504 of the Rehabilitation Act provides that "[n]o otherwise qualified individual with a disability … shall, solely by reason of her or his disability, be excluded from the participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving Federal financial assistance…."[12]

Under both the ADA and the Rehabilitation Act, Congress mandated promulgation of implementing regulations. Federal regulations provide:

- Design and construction. Each facility or part of a facility constructed by, on behalf of, or for the use of a public entity shall be designed and constructed in such manner that the facility or part of the facility is readily accessible to and usable by individuals with disabilities, if the construction was commenced after January 26, 1992.

- Alteration. Each facility or part of a facility altered by, on behalf of, or for the use of a public entity in a manner that affects or could affect the usability of the facility or part of the facility shall, to the maximum extent feasible, be altered in such manner that the altered portion of the facility is readily accessible to and usable by individuals with disabilities, if the alteration was commenced after January 26, 1992.[13]

Voting equipment has been found to fall within the expansive definition of "facility" contained in the regulations.[14] Accordingly, election officials must employ means that make voting equipment "readily accessible to and usable by individuals with disabilities."[15] However, existing precedents do not require election officials to provide voting equipment "that would enable disabled persons to vote in a manner that is comparable in every way with the voting rights enjoyed by persons without disabilities."[16] The next few years will likely clarify the precise requirements of both HAVA and these earlier statutes with respect to the accessibility of voting systems, as courts hear challenges to the various choices made by elections officials across the country.

## The "Voluntary Guidelines"

*The Access Board is a federal agency committed to promulgating accessible design.*

In the meantime, federal agencies have issued two sets of voluntary guidelines for voting system design. In 2002, the Federal Elections Commission ("FEC") in conjunction with the United States Access Board issued a set of technical standards and recommendations called the 2002 Voluntary System Standards ("VSS").[17] The "Accessibility" provisions (Section 2.2.7) of the VSS were divided into two categories: those that apply to all voting systems and those that apply only to direct recording electronic ("DRE") voting systems. The "Common Standards" section (2.2.7.1) includes six requirements that address the appropriate height of the voting system, the maximum distance the voter should have to reach to be able to use the system, and the accessibility of the controls to the voter.[18]

The "DRE Standards" section (2.2.7.2[19] ) includes requirements for accessible voting systems that can be summarized as follows:

- The voter shall not have to bring in his or her own assistive technology in order to vote privately and effectively using the DRE system.
- The system shall provide an audio output that accurately communicates the complete content of the ballot and instructions; supports write-in voting; enables the voter to edit, review, and confirm his or her selections; allows the voter to request repetition of information; supports the use of external headphones; and provides adjustable volume controls.
- When a system uses a telephone-style handset to provide audio information, it should provide a wireless coupling for assistive devices used by people who are hard of hearing.
- The system should avoid electromagnetic interference with assistive hearing devices.
- The system should allow for adjustments to be made to the display image, specifically the image's contrast ratio, colors, and size of text.
- If the system uses a touch-screen, it should also provide an alternative tactile input option that will be easy to operate for individuals with limited motor skills (*i.e.*, lightweight, tactilely discernible, requiring little force and dexterity, operable with one hand).
- If the system requires a response from the voter within a set period of time, it must alert the voter before time is up and allow the voter to have additional time if necessary.
- If the system uses an audio cue to alert the voter of an error or confirmation, it must also provide a visual cue for voters to accommodate voters with hearing impairments.

- If the system's primary means of voter authentication uses biometric technology that requires the voter to have certain biological characteristics, a secondary means of voter authentication must be made available.

In December 2005, the EAC issued a new set of standards for voting systems, the 2005 Voluntary Voting System Guidelines ("VVSG"). These guidelines reaffirm criteria set forth in the 2002 VSS and push certain standards a step further by insisting that a standard "shall," rather than "should," be followed. In addition, the VVSG's requirements apply to all voting systems, not just DREs, and establish detailed parameters for each recommended accessibility feature. The most important new specifications can be summarized as follows:

- Machines shall be capable of displaying text in at least two font sizes, (a) 3-4 millimeters, and (b) 6.3-9.0 millimeters.[20] Sans-serif fonts are preferable to stylized fonts.[21]

- All machines must be capable of displaying information using a high-contrast display with a ratio of at least 6:1.[22]

- Any buttons and controls on a voting system must be discernible by both shape and color.[23]

- Machines must provide an audio-tactile interface that replicates a standard visual ballot and allows voters to access the full range of features and capabilities in a standard visual ballot. In addition, systems must allow a voter to pause and resume an audio presentation and to rewind the presentation to a previous contest.[24]

- Default volume level for machines should be set between 40 and 50 dB. Voters should be able to adjust volume up to a maximum level of 100 dB in increments no greater than 10 dB.[25] In addition, machines must be programmed to allow voters to vary the speed of an audio presentation.[26]

- Voters should be able to watch and listen to a ballot at the same time.[27]

- For optical scan systems, "if voters normally feed their own optical scan ballots into a reader, blind voters should also be able to do so."[28]

## DISABILITY DEMOGRAPHICS

A large proportion of the voting-age population would benefit from a voting system accessible to people with disabilities. According to the 2000 Census, at least 44.5 million adult residents of the United States (ages 21 and above) have some form of disability.[29] Moreover, because many disabilities are associated with advanced age, a rapidly aging population stands to produce dramatic increases in the number of voters with disabilities.[30] The statistics in Table A1 confirm the

magnitude of the voting-age population with disabilities and/or special language needs.

TABLE A1

U.S. VOTING-AGE POPULATION WITH DISABILITIES AND LANGUAGE NEEDS

| People over 18 who: | Millions of people |
|---|---|
| Have trouble seeing[31] | 19.1 |
| Have trouble hearing [32] | 30.8 |
| Experience physical difficulty, including trouble grasping or handling small objects[33] | 28.3 |
| Speak English less than "very well"[34] | 17.8 |
| Live in "linguistically isolated households"[35] | 9.2 |

In addition, the accessibility of voting systems affects not only those with permanent disabilities, but also the millions of voters with temporary disabilities or conditions that would not formally be considered disabilities. For example, a voter with a broken arm who has limited use of her hand, or who has forgotten her reading glasses and cannot read small text, or who has minimal reading skills can vote more easily and effectively as a result of more accessible voting systems. With this impact in mind, the VVSG include many requirements for *all* voting systems (not just those considered "accessible") that increase ease of access for people who are already fully able to vote without assistance.

At the same time, a voting system may provide accessibility to voters with various disabilities, yet still not be easy to use. For instance, an audio system may provide accessibility to voters with vision impairments, but if the system's audio jack is hidden on the back of the machine, the system cannot be considered very usable. Similarly, when creating voting systems for individuals with vision impairments, considerations of accessibility alone are not enough. As Mary Theofanos and Janice Redish have described with respect to website accessibility, "the diversity of vision needs and the resulting adaptations that low-vision users require mean that there are no simple solutions to making web sites work for everyone."[36] For the same reasons, it is difficult to make voting systems that work for all voters with vision impairments. Voting machines must enable voters with vision impairments to easily adjust the system to their particular needs to take full advantage of accessibility features.[37]

## METHODOLOGY

To assess the various voting system architectures, the Brennan Center's team of consulting experts created a set of accessibility criteria drawn from existing accessibility guidelines (including both those specific to voting systems and general information technology guidelines), such as the VSS 2002,[38] Section 508 of the Rehabilitation Act,[39] and the VVSG (2005),[40] as well as additional considerations developed through team discussions. These criteria are posed as questions that can help election officials and advocates compare specific systems for use on Election Day.

Next, through a combination of group discussions and one-on-one interviews with the authors, the team of consulting experts provided their impressions of systems' accessibility, which are reflected in this report. Experts considered not only how an individual feature might affect accessibility, but also how a system works as a whole. Many voting systems are only accessible if jurisdictions implement certain procedures or modify systems in specific ways. In evaluating systems, the team considered whether certain modifications or procedures are needed to render an otherwise inaccessible system accessible.

In addition, each system was first considered as a self-contained product that did not require the voter to bring her own special adaptive technology. If headsets are needed to hear an audio version of the ballot, for example, those headsets would need to be provided at the polling place in order for that voting system to be considered accessible without effort on the part of the voters. This assumption mirrors the Access Board's definition of a "self-contained product" from 1194.25(a) of the Section 508 Standard:

> Self-contained products shall be usable by people with disabilities without requiring an end-user to attach assistive technology to the product. Personal headsets for private listening are not assistive technology.[41]

Beyond the most basic accessibility features of a system, however, some observers believe that a voting system should allow a voter to use her own assistive technology, if desired (*e.g.,* by supplying standard ports to connect this equipment to the voting system). Others have raised three arguments against such an approach. First, some experts argue that voting systems are intended to be self-contained, and voters should not be required to bring any special equipment to the polling place. Second, very few industry standards presently govern the design of connections for assistive technology. At this time, the only standard jacks included in federal standards (either the VSS or VVSG) are audio jacks for personal headsets. Third, security concerns exist about including ports to connect uncertified equipment to a voting system, and the risks involved in installing the drivers or other software usually needed to allow assistive technology to operate. Without attempting to resolve this debate, we assessed the extent to which each system allows a voter to make use of personal assistive technology to reduce barriers to access.

Last, we offer an introductory sketch of accessibility features currently provided by vendors and an analysis of how those features might help ensure compliance with our accessibility criteria. To obtain this information, we first culled information from any available product information published by vendors. We then conducted initial telephone interviews with vendors and usability experts on the status and utility of available features. Next, we sent each vendor a written summary of all compiled research on their machines. Vendors commented upon those reports, and their changes or comments are reflected here.

## VOTING ARCHITECTURE ANALYZED

This chapter analyzes the following six voting system architectures:

- Direct Recording Electronic ("DRE")
- Precinct Count Optical Scan ("PCOS")
- Ballot Marking Device ("BMD")
- DRE with Voter-Verified Paper Trail ("DRE w/ VVPT")
- Vote-by-Mail
- Vote-by-Phone

The specific design of these systems varies greatly with each manufacturer's models. With respect to the voter's experience, however, the systems can be categorized based upon the primary medium through which the voter interacts with the system to mark and cast the ballot. We consider the features of each type of system individually, but group the systems based on their primary interface as follows:

1. Computer-Based Interface:
   - DRE
2. Paper-Based Interface:
   - PCOS
   - Vote-by-Mail
3. Hybrid Interface:
   - BMD
   - DRE w/ VVPT
4. Telephone-Based Interface:
   - Vote-by-Phone

# ANALYSIS

## COMPUTER-BASED SYSTEMS

With certain exceptions, computer-based voting systems provide greater accessibility to all disabled voters than do paper-based systems. As discussed in greater detail below, the flexibility inherent in computer-based systems allows voters to choose and mix features, a capacity that dynamically increases accessibility for voters with disabilities. In particular, computer-based systems facilitate voting for people with visual impairments: The size of text can, for example, be electronically enlarged. Display screens can be set at a high contrast that clarifies and emboldens words and images. Computer-based systems can provide audio versions of instructions for voting and of the ballot itself. Other voters can also reap the benefits of computer-based systems. Voters who are not comfortable reading English can choose to read or hear their ballots instantly in a different language. Voters with limited motor capacity need not handle paper or pencil. Often, voters with disabilities can access these features and vote on their own without the assistance of a poll worker or personal aide.

Computer-based systems permit voters to use a range of visual, auditory, and tactile options simultaneously. For example, a voter who cannot read well may choose to hear instructions read out loud, but can retain the ability to select a candidate visually from the screen based on her recognition of a candidate's name. Drafters of the VVSG have recognized the potential of mixing modes in this fashion and include a requirement that accessible systems allow visual and audio streams to be used simultaneously.[42] If designed to do so, computer-based systems can fulfill this requirement with relative ease.

Despite these considerable advantages, computer-based systems can present certain barriers for people with disabilities. Navigation of computer screens often requires that voters use controls that require hand-eye coordination – a touch-screen or a mouse – to select their choices. To operate these controls successfully, voters must have the visual facility to see a cursor move across a screen or to distinguish between virtual buttons on a display and the complementary motor-control necessary to move a mouse or press distant areas on a touch-screen.

The most popular computer-based DRE systems already provide an auxiliary control pad for voters with visual or mobility and coordination impairments. In theory, voters can discern each part of these auxiliary controls using only their sense of touch. The controls' utility varies from machine to machine. Designers can vary the shape of each control mechanism to allow voters to discriminate between controls without looking at them. Voters can activate such controls with minimal force and without fine motor control. Moreover, a button similar to a computer tab key can allow voters to click their cursor between one selection and another without having to move a mouse or touch a screen.

The following questions should be considered in assessing the accessibility of computer-based voting systems:

### 1. Can the system be physically adjusted to meet a voter's access needs?

The answers to this question depend on the ease with which a voter or poll worker can: (a) adjust the height of the computer screen, (b) tilt or rotate the screen, or (c) remove the screen and input controls from a tabletop surface so that a voter can hold the system in her lap and even vote outside the polling place, *i.e.*, "curbside."

DREs fall into two categories: Certain systems, including Avante's Vote Trakker,[43] Sequoia's AVC Edge,[44] and Accupoll's Voting System 1000,[45] sit stationary on a table or stand. Voters cannot readily adjust a stand's or table's height, and such machines are only accessible to voters in wheelchairs if precincts set some surfaces at lower heights before polls open. Some of these systems, including Sequoia's AVC Edge,[46] also address height concerns by allowing their screens to tilt upward and downward. With the exception of Avante's[47] machines and the systems once manufactured by Accupoll,[48] such systems are sufficiently portable for a poll worker to set them up curbside if necessary.[49]

Other systems, such as Hart Intercivic's eSlate,[50] ES&S, Inc.'s iVotronic,[51] and Diebold's AccuVote-TSX unit,[52] do not need to rest on a table. These systems can be set up to provide a lightweight tablet (ranging from roughly 10–15 lbs.) that the voter can place on her lap or other suitable surface. This portable module includes the screen and all of the necessary input controls. These systems are also sufficiently portable to allow for curbside voting.

### 2. Does the system allow voters to adjust the visual presentation of information contained in the ballot or in voting instructions?

Although all computer-based systems could offer a range of malleable viewing options, each DRE model differs in the alternatives it provides for users with vision impairments. The VVSG require that certified systems comply with certain requirements concerning the presentation and adjustability of visual outputs. In particular, the VVSG require that certified systems provide an enhanced visual display that includes a high-contrast presentation, a black-and-white display option, and at least two font size options of a minimum size.[53]

Many models have already met the requirements prescribed in the VVSG. DREs produced by Sequoia,[54] Diebold,[55] Hart Intercivic,[56] ES&S, and Accupoll,[57] have high-contrast electronic image displays with a contrast ratio of 6:1 or greater. DREs manufactured by Accupoll,[58] Avante,[59] Sequoia,[60] and ES&S[61] have electronic display options that allow for either a black-and-white-only display or a color display that provides the voter with a means to adjust colors. These features can be made available to voters using machines made by Diebold[62] and Hart

Intercivic[63] but elections officials must ensure that they are incorporated in the ballot's design when it is initially developed.

DREs made by Accupoll[64] and Avante[65] provide at least two font sizes – one with capital letters of at least 6.3 mm and one with capital letters of between 3.0 and 4.0 mm – using a sans-serif or similar font. Models produced by Diebold,[66] Sequoia,[67] Hart Intercivic[68] and ES&S[69] can also vary font size, but officials must request that this feature be implemented during initial ballot design.

### 3. Does the system allow voters to adjust the audio presentation of information contained in the ballot or in voting instructions?

Audio outputs can be adjusted in four ways. First, systems can allow voters to adjust the volume of the audio playback. Indeed, the VVSG requires systems to do so.[70] DREs produced by Sequoia,[71] Diebold,[72] Hart Intercivic,[73] ES&S,[74] Avante[75] and Accupoll[76] provide volume adjustability as a standard feature: volume can be amplified up to a maximum of 105 dB SPL and automatically resets to a default level after each voter completes her ballot.

Second, auditory outputs can be recorded in either digitized or computer-synthesized speech. Digitized speech is produced by recording one or more human voices and then playing such recordings back through the computer's digital system. This type of speech is reportedly easier to understand than synthesized speech, a rendering that can sound flat and unfamiliar.[77] Digitized speech is already available on DRE systems manufactured by Sequoia,[78] Diebold,[79] Accupoll,[80] Hart Intercivic[81] and ES&S.[82]

Third, certain systems allow the voter to control the rate of speech in the audio output, as recommended in the VVSG.[83] People who are accustomed to interacting with technology through an audio interface can "listen faster" and thus expedite the otherwise potentially lengthy voting process. This feature is available on Avante's,[84] Sequoia's[85] and Diebold's[86] DRE systems. According to experts, speech control has until now been associated with systems that use synthesized speech. However technologies are now available to allow digitally recorded human speech to be played at different speeds without changing the tone or creating a high-pitched, chipmunk effect.[87]

Finally, the use of different voices for instructions and for ballot selections – for example, a candidate's name – allows some voters to expedite the voting process. Voters accustomed to using audio interfaces can speed up audio recordings so that they can skim text for breaks or keywords that indicate a new contest. In this way, voters "scan with their ears" in the same manner that readers quickly scan and review a page of text.

This feature can be made available on systems manufactured by Avante,[88] Sequoia,[89] Diebold,[90] Accupoll,[91] Hart Intercivic[92] and ES&S,[93] but must be requested by election officials during ballot design.

### 4. Does the system provide an audio output/tactile input alternative access option to meet the needs of individuals with visual impairments or other difficulties reading?

Voters who cannot see or read information presented on a visual display need an alternate, non-visual way both to receive and to input information into DREs. All major manufacturers of DREs (Avante,[94] Sequoia,[95] Diebold,[96] Accupoll,[97] Hart Intercivic[98] and ES&S[99]) address this issue by providing a version of their ballots through an Audio Tactile Interface ("ATI"). ATIs allow voters to hear candidate choices via an audio ballot, rather than seeing them on a display screen, and to make their choices without any cursor or touch-screen by using separate, tactilely discernible controls.

The 2002 VSS contained detailed criteria for audio ballots, all of which have been reiterated in the VVSG. The audio ballots were required to communicate the complete contents of the ballot via a device affixed to an industry standard connector of a 1/8 inch jack, provide instructions to the voter, enable the voter to review and edit her input, pause and resume the playback, confirm that the edits reflect her intent, and allow the voter to request repetition of any information provided by the system.[100] Still, those systems manufactured under the VSS have produced complaints of badly worded prompts, poorly recorded or poorly digitized speech, and poor navigation options, any of which can make an audio ballot difficult to understand or follow.[101] Where possible, election officials should conduct testing with voters with visual disabilities to assess the audio ballots available on different machines prior to purchase.

### 5. Does the system provide controls suitable for voters with limited fine motor skills?

The touch-screen navigation that is required by most DRE systems poses significant barriers to access for persons with limited fine motor skills. Because the boundaries of selections on the screen are not tactilely discernible, and it is relatively easy to make an erroneous selection by touching the screen outside the boundaries of the intended "button," voters who can use their hands but have limited fine motor control face significant difficulties in voting successfully and independently. For example, individuals with tremors or other movement disorders that require them to brace their hand when pointing or pressing a button may encounter difficulties with touch-screens because they cannot rest their hand on the screen to make selections. If a touch-screen requires direct touch from the human body rather than a push from any object made of any material, then individuals who use head sticks or mouth sticks would be unable to use the touch-screen. Thus, for voters without the use of their hands, the touch-screen cannot be used to make selections at all. In all these cases, there must be an alternative input control available.

Manufacturers solve this problem by allowing voters to input selections using the auxiliary control panel originally designed for ATIs. Voters can use the alternate

controls on this device to indicate their choices and, in certain machines, retain the ability either to see their ballot on a display screen or to hear their ballot through earphones. Hart Intercivic's eSlate goes a step beyond and makes its standard control panel accessible to voters with limited fine motor skills: Voters move between selections on an electronic screen by turning a dial; separate buttons exist for selecting a certain candidate or response and for casting a completed ballot.[102]

Certain voters cannot input selections with their hands at all, however, and must use a separate device to input information. Some machines, including those manufactured by Accupoll,[103] Sequoia,[104] Hart Intercivic[105] and Avante,[106] include a "dual switch input option," a jack for a voter to insert such a device. Voters can, for example, attach a sip-and-puff device, which allows them to indicate choices by applying varying amounts of pressure to a straw inserted in the mouth. Other users may use a blink switch that allows them to operate one or two switches by blinking their eyes. In both cases the switches can be used to control the voting machine if it is set up to be controlled with one or two switches.

Switch input devices can present their own usability concerns for certain voters. Such devices require voters to use a control that can communicate a limited number of messages for two types of actions, ballot navigation and selection. A voter using a single, rather than dual, switch input device may not have the ability to scroll backward and forward to revisit earlier answers and might have to restart the ballot completely to change a choice. For this reason, voters benefit from voting systems that can interpret switches that transmit at least two discrete messages: forward/select and backward/select. This flexibility can increase the speed and usability of the voting system for voters using auxiliary devices. Election officials should ensure that dual switch input devices can be used on the system chosen.

### 6. Does the system allow simultaneous use of audio and visual outputs, in other words, can a voter to see and hear a ballot at the same time?

Many voters, particularly those with low literacy levels, limited English skills, or mild vision impairments, can benefit from both hearing and seeing a ballot. For that reason, the VVSG has required that all audio ballots and ATIs be synchronized with a standard visual output.[107] This feature is presently available on systems manufactured by Accupoll,[108] ES&S,[109] Diebold[110] and Hart Intercivic.[111] According to its representatives, Sequoia plans to implement this feature sometime in 2006.[112]

### 7. Does the system allow voters to input information using a tactile control device while still receiving visual, rather than audio, output?

Voters with limited fine motor control may not need to listen to an audio ballot and may prefer to enter their selections using an auxiliary tactile control device,

while still receiving their ballot through a standard visual display. This feature currently exists on the DRE systems manufactured by Hart Intercivic,[113] Diebold[114] and Accupoll.[115] According to its representatives, Sequoia plans to implement this feature sometime in 2006.[116]

### 8. Can a voter choose and change accessibility and language options without the assistance of a poll worker?

One of the advantages of a computer-based interface is that it can provide a range of options and can allow those options to be selected by the voter privately and independently. Similarly, the voter should be able to correct her unintended selection of a feature independently. For example, if a voter who has already made some but not all of her selections decides that she would prefer a larger text size, but must return to a preliminary screen to alter the size of the text to continue voting successfully, such a transition may be prohibitively confusing, require assistance from a poll worker, or lead to failure.

Some vendors have anticipated the need for flexibility and have designed systems that allow voters to choose and switch between features with ease. Accupoll allows voters to switch languages, adjust volume, and magnify or shrink text size at any time.[117] Avante users can change visual and audio settings at any time.[118] Diebold users can select and change visual features at any time, but cannot change audio features without poll worker assistance.[119] ES&S's and Hart Intercivic's systems ask voters to select their preferred features at the beginning of the ballot, but do not allow voters to change features later in the voting process.[120] According to Sequoia's representatives, the updated version of the AVC Edge will allow voters to choose and manipulate all features at all times.[121] With the exception of Hart Intercivic's eSlate and ES&S's iVotronic, computer-based systems require that ATIs be initialized by a poll worker each time a voter requests a change in the settings in use.[122]

### 9. Is the system's audit function accessible to all voters?

All DREs allow voters to review an electronic record of their cast ballots. Those records can also be read back via audio inputs to blind voters and can be presented in an enhanced visual display to voters with vision impairments.

## PAPER-BASED SYSTEMS

Paper-based systems, which include systems that use optical scan ballots and Vote-by-Mail ballots, create barriers to voters with disabilities that are not as easily remedied as those presented by computer-based systems. The barriers imposed by these systems result principally from four features of the voting experience. First, with both optical scan and Vote-by-Mail systems, the paper ballot itself must be printed prior to Election Day and cannot be adjusted to address the needs of a particular voter. For voters with visual impairments, requesting and using large-print paper ballots may sacrifice a measure of their privacy: officials

know who request large-print ballots, and if only a small number of individuals do so, officials can discern voters' personal selections after polls have closed. Like voters with vision impairments, voters who require alternate languages may need to request a different ballot pre-printed in their language and may encounter a similar privacy concern. In sum, despite the use of large-print ballots and assistive devices like magnifying glasses, many voters with vision impairments may still have greater difficulties reading the paper ballot than they would reading an enhanced electronic visual display.[123]

Second, paper-based systems require voters to read the ballot. Some jurisdictions provide recordings of the ballot to facilitate voting for those with visual impairments.[124] Even when made available, auditory instructions for paper-based systems are presently produced by a cassette machine rather than by a computer-based audio system, and voters cannot change the speed of the audio recording nor skip forward or backward with ease. More importantly, voters with visual impairments cannot review their ballots for accuracy once they have been marked without another person reading the contents to them because no paper-based systems allow an auditory review of voters' input. For some voters with visual impairments this barrier can mean an absolute loss of privacy and independence.

Third, paper-based systems require voters to mark the ballot manually. Voters with coordination or vision problems may require significant assistance to complete this task. In addition, voters with cognitive disabilities have an especially difficult time marking ballots that ask voters to follow an arrow across a page and select a candidate. Many voters with learning disabilities may struggle to perform this kind of visual tracking successfully.

Finally, many paper-based systems require voters to feed their marked ballots into a scanner, and voters with impairments relating to vision, mobility, or coordination will experience difficulties in completing these tasks. To initiate and complete scanning, voters must have the visual and physical facility to grasp a ballot, walk across a polling station, and insert their ballot into a scanner. Many voters will find their privacy and independence threatened as they seek the assistance of another person in order to complete the scanning process.

The following questions should be considered in assessing the accessibility of paper-based voting systems:

### 1. Can the system be physically adjusted to meet a voter's access needs?

For those voters with disabilities that do not preclude them from handling or seeing paper, paper ballots are easy to position so that they can be seen and marked. The polling place need only include a selection of writing surfaces set at varying heights.

However, systems that require a voter to physically handle paper are fully inaccessible to those voters who have such profound motor coordination disabilities that they are unable to grasp or otherwise manipulate a paper ballot. Such voters cannot clutch a ballot handed to them by a poll worker or operate a pen or marking device. Nor can these voters transport a ballot across a polling station and feed the ballot into a tabulator. Because they are unable to execute the basic mechanics of paper ballot voting without considerable assistance, voters with significant motor control impairments are unable to vote in a private and independent manner.

Voters with significant visual disabilities have equally prohibitive difficulties with paper ballots. Without assistance, such voters are unable to read instructions and candidate choices or to mark their selections. No currently available physical adjustment to the paper ballot sufficiently lowers these barriers.

In addition, paper-based systems may pose specific barriers to certain voters who use wheelchairs. Most optical scan systems include a precinct-based scanner into which the voter must insert her ballot to be counted, and these scanners can be inaccessible to voters with high spinal cord injuries. Scanners, including those manufactured by Avante,[125] Diebold,[126] Sequoia,[127] and ES&S,[128] often sit atop a solid ballot box that stands at waist height. The scanner's feeder is situated at the front of the box, and no ballot box provides space under this feeder for a wheelchair. Thus, voters in wheelchairs cannot roll up to a scanner and face it. Instead, voters in wheelchairs must roll up beside a scanner, rotate their torsos, and place the ballot into the feeder slot. Many voters with high spinal cord injuries cannot move in this fashion and thus cannot vote without third-party assistance.

Though they present many of the accessibility concerns inherent in any paper-based system, Vote-by-Mail systems provide unique, physical benefits for voters with certain disabilities, particularly mobility impairments. These are the only systems that do not require travel to a polling place. The voter completes the voting process in her own physical environment with more accessible writing surfaces or assistive devices tailored to that voter's specific needs.

### 2. Does the system allow voters to adjust the visual presentation of information contained in the ballot or in voting instructions?

Once the paper ballot is printed, the size and contrast of the text can no longer be adjusted. To circumvent this limitation, jurisdictions can print ballots with a range of visual presentations, as any vote tallying system can be programmed to count ballots with enlarged print, different colors and contrast ratios, multiple languages, or other special options. Scanners must be programmed to read such ballots, and the jurisdiction must print any special ballots in advance and make them available upon request. In addition, though Vote-by-Mail systems provide certain advantages for voters with physical limitations, voters with visual impairments may struggle to complete the voting process without assistance. These

voters may not be able to read ballot instructions and candidate choices, or know what they have marked, and may need to sacrifice their privacy and independence to cast their ballots in a Vote-by-Mail system.[129]

### 3. Does the system allow voters to adjust the audio presentation of information contained in the ballot or in voting instructions?

The advent of BMDs – which allow voters with vision disabilities and voters with limited motor skills to mark a ballot using an auxiliary tactile control – has effectively superseded most efforts to make paper ballots more accessible through audio recordings.[130] Without the kind of interface provided by a BMD, many voters with severe visual or motor coordination impairments cannot mark a paper ballot without assistance from another person. The use of "tactile ballots" with PCOS systems seeks to address this barrier as discussed below, but such devices do not allow voters to review their marked ballots.

### 4. Does the system provide an audio output/tactile input alternative access option to meet the needs of individuals with visual impairments or other difficulties reading?

Paper-based systems do not have audio output or tactile input, and without some additional component added to the system, cannot provide it. This is true for all of the systems – PCOS and Vote-by-Mail – that require the voter to mark a paper ballot. However, certain small-scale innovations have been developed to help people with visual disabilities to mark paper ballots, including "tactile ballots." In such systems, a paper ballot is accompanied by an overlay with tactile markings and an audiotape with a description of the ballot to guide the voter in marking her ballot. The advantage of using such add-ons is that the marked ballot is indistinguishable from all of the others and, once cast, can be counted in the same manner.

The International Foundation for Election Systems has developed a tactile ballot template that can be used to accommodate voters with visual impairments.[131] These templates are currently in use in Rhode Island, which uses optical scan systems, for blind and visually-impaired voters.[132] When used with a Braille instruction sheet, tactile ballots allow some voters who are both blind and deaf to mark their ballots without third-party assistance.

There are, however, several disadvantages. The sequential audiotapes force voters to proceed through the ballot at the rate of the recorded playback, rendering the voting process slower for voters using these systems than for voters using a digital audio playback. More importantly, blind and certain low-vision voters cannot review the marked ballot, and must trust that it is marked correctly or obtain the assistance of another person to do so, with a consequent loss of independence and privacy.

Because Vote-by-Mail ballots are marked in the voter's home, she must have any special assistive systems already available if she wishes to vote without assistance. For example, a voter might have a system to scan a paper form and have it read back to them. But, as with tactile ballots, voters with severe visual impairments may not be able to review their marked ballots. For voters without any assistive devices, moreover, it may be impossible to vote without assistance.

### 5. Does the system provide controls suitable for voters with limited fine motor skills?

Paper-based systems do not have controls to mark the ballot and instead require the voter to use a pen or pencil to mark it. Such systems are thus inaccessible to many voters with limited fine motor skills. In addition, all of these systems (including BMD systems) require the voter to place the marked ballot into an optical scanner. Voting systems that require a ballot to be grasped, transported across a polling place, and fed into a scanner create obvious difficulties for voters without fine motor skills.

### 6. Does the system allow simultaneous use of audio and visual outputs, in other words, for a voter to see and hear a ballot at the same time?

Theoretically, election administrators could provide voters with a scanner of some kind that could convert ballot text into audible speech. No such scanner is currently on the market, however, perhaps because BMDs serve the same essential purpose at a lower cost.

### 7. Does the system allow voters to input information using a tactile control device while still receiving visual, rather than audio, output?

Unless a voter can use a tactile paper ballot, this feature is essentially inapplicable to paper-based systems, which are not amenable to fully tactile controls.

### 8. Can a voter choose and change accessibility and language options without the assistance of a poll worker?

Unlike a computer display, paper ballots cannot be dynamically altered to change the size, color, or language of the text at the time when a vote is cast.

With respect to language options, however, if all of the languages used in the precinct are printed on each ballot, the voter can make use of any of these options in a PCOS or Vote-by-Mail system. If not, she must request her desired language either at the polling place (PCOS or BMD) or in advance (Vote-by-Mail). Large text or other special versions must also be requested in the same manner.

Similarly, if a voter needs to change the format of the paper ballot he is using during the voting process, in most cases he must request a new, blank ballot. For example, a voter who discovers that she is having trouble reading the ballot might request a large-print version, if one is available. Similarly, if the voter has already marked the ballot erroneously, she must ask for a new ballot. Unlike most computer-based systems, paper-based systems require a voter to seek and obtain such assistance and to discard all work on the original ballot.

In a Vote-by-Mail system, requesting a new or different ballot can involve a trip to the elections office, requiring significant effort on the part of the voter. In Oregon, however, the only state that currently uses such a system, replacement ballots can be requested by calling a toll-free hotline or a County Board of Elections Office.[133] If a voter calls more than five days before an election, her ballot will be sent to her in the mail. If a voter calls within five days of an election, she must travel to a County Board of Elections Office to pick up her ballot. Such a trip could prove prohibitive for some disabled voters without transportation.

#### 9. Is the system's audit function accessible to all voters?

Any voter who can see and read a paper ballot can audit the ballot simply by looking at it. Voters with vision disabilities or trouble reading may need a machine to translate markings on a paper ballot into an enhanced visual display or audible reading of those markings. No such scanner, other than the BMD systems described below, currently exists.

## HYBRID SYSTEMS

To determine the accessibility of both hybrid systems analyzed in this section – BMD and DRE w/ VVPT – it is best to think of each hybrid system in terms of the system architectures they combine. BMD systems integrate a computer-based system with a defining feature of paper-based systems: namely, voters use a computer to mark a paper ballot they feed into a scanner to be processed and counted. Similarly, DREs w/ VVPT make use of both computer- and paper-based systems. DREs w/ VVPT incorporate a paper-based system as a means by which a voter can verify her selections prior to casting her vote.

### OVERVIEW OF BMD

Like a DRE, BMD systems allow a voter to make her selections on a computer. BMD systems print the marked ballot for the voter, who must then feed it into a scanner to be counted. BMDs thus provide the significant accessibility features of a DRE, but still require that voters overcome the barriers inherent in scanning paper ballots. Indeed, if the marking process were the end of the voting process, the use of paper ballots coupled with BMDs would present no greater barriers to voters with disabilities than DREs.

## ANALYSIS OF BMD

### 1. Can the system be physically adjusted to meet a voter's access needs?

Once a BMD prints a marked ballot, the system poses unavoidable challenges to voters who cannot transport a ballot across a polling station. Prior to that point in the voting process, however, voters interact with a BMD exactly as they would with a computer-based DRE system. The voter has the same opportunities to (a) adjust the height of the computer screen, (b) tilt or rotate the screen, or (c) remove the screen and input controls from a tabletop surface to hold the system in her lap. ES&S's Automark includes a screen that can be tilted upward and downward,[134] and Populex's BMD system, at 15 lbs., can rest in a voter's lap or be easily transported to allow for curbside voting.[135]

### 2. Does the system allow voters to adjust the visual presentation of information contained in the ballot or in voting instructions?

BMDs present all ballot information in an electronic format. In theory, voters can adjust this electronic ballot in all the ways one can adjust a DRE's presentation to allow greater access. Both the Automark and Populex BMDs have high-contrast electronic image displays with a contrast ratio of 6:1 or greater.[136] In addition, both machines allow for either a black-and-white display or a color display that provides the voter with a means to adjust colors.[137] Populex provides two font sizes, one with capital letters of at least 6.3 mm and one with capital letters of between 3.0 and 4.0 mm, both in a sans-serif or similar font.[138] The Automark's screen supports large-font displays and font sizes can be varied by the voter if elections officials request that this feature be implemented during initial ballot design.[139] Populex and Automark users can also magnify any part of their ballots by pressing a zoom button at any time.[140]

### 3. Does the system allow voters to adjust the audio presentation of information contained in the ballot or in voting instructions?

Users can adjust the volume of the Automark and Populex BMDs to a maximum of 105 dB SPL.[141] Volume is automatically reset to a default level after each voter completes her ballot.[142] Both BMDs also allow voters to accelerate its audio recording in order to expedite the voting process.[143]

### 4. Does the system provide an audio output/tactile input alternative access option to meet the needs of individuals with visual impairments or other difficulties reading?

Both the Automark and the Populex BMDs come with ATIs and have dual switch input capabilities.[144] On the Automark's ATI, four blue arrow keys are used to move between choices and surround a blue square button that is used to make selections. All buttons are also labeled in Braille.[145] Populex provides a modified

calculator keypad as its ATI.[146] For voters who cannot use a standard ATI, the Automark also provides dual switch input capacity.[147]

### 5. Does the system provide controls suitable for voters with limited fine motor skills?

BMDs allow voters with limited motor skills to mark their ballots without the assistance of an aide or poll worker. Still, voters who need BMDs to mark their ballots often lack the dexterity necessary to complete the voting process independently once the ballot has been marked. Voters must retrieve their ballots from a BMD, travel to a scanning station, and feed their ballots into a scanner. Thus, many voters with limited motor skills may require a poll worker or aide to handle these tasks, and this assistance could diminish their privacy and independence.

BMD manufacturers have attempted to address the privacy concern by providing a cover sleeve that is placed over the ballot.[148] If a voter cannot clutch a ballot well enough to place it in a plastic sleeve, another person can insert the blank ballot into a privacy sleeve for the voter at the start of the voting process. The top two inches of the ballot protrude from the cover. The person who provides such assistance can then proceed with the voter to the BMD, insert the two-inch overhang into the feeder slot, and allow the machine to draw in the unmarked ballot. The privacy sleeve is left hanging off the lip of the feeder slot and, once a voter has finished marking the ballot, the BMD automatically inserts the marked ballot back into the privacy sleeve.

At that point, the person who is assisting the voter can transport the covered ballot across the polling place to a scanner, insert the front two inches of the ballot into the scanner, and allow the scanner to draw in and count the voter's ballot. According to ES&S and Vogue's representatives, at no point will that person see any of the markings on the voter's ballot.[149] Although cover sleeves may safeguard a voter's privacy, such protection could come at a stiff price for jurisdictions. Managing the use of privacy sleeves places a high burden on poll workers. Not only must workers manage the distribution of sleeves, but they must also shadow any voter who needs a sleeve through every step of the voting process. Nor does the privacy sleeve restore the independence lost by the voter who cannot complete the voting process without assistance.

### 6. Does the system allow simultaneous use of audio and visual outputs, in other words, for a voter to see and hear a ballot at the same time?

This feature is available on the Automark and Populex BMD systems.[150]

### 7. Does the system allow voters to input information using a tactile control device while still receiving visual, rather than audio, output?

This feature is available on the Automark.[151]

### 8. Can a voter choose and change accessibility and language options independently without the assistance of a poll worker?

The Populex system allows the voter to magnify text and adjust the audio presentation at any time.[152] The Automark allows voters to adjust the audio presentation at any time, and a button on its touch-screen allows voters to switch between two font sizes or magnify text.[153]

### 9. Is the system's audit function accessible to all voters?

Both the Automark and Populex BMDs allow voters to review the marks on their ballots. According to Vogue and ES&S representatives, the Automark BMD is sold with a standard scanner that reviews the darkened bubbles on the ballot's face and translates those marks into an enhanced visual display or an audio rendering of a voter's choices.[154] A voter need only reinsert her ballot to activate this feature.[155] The Populex BMD prints its marked ballots with a barcode that reflects a voter's selections.[156] Voters can swipe this barcode under a scanner that converts its contents into an audio output that can be reviewed with headphones or on an enhanced visual display. To activate these features, a voter needs only the visual and physical dexterity to swipe her marked ballot under Populex's scanner. For voters with limited vision or limited fine motor control this final step may prove difficult and require assistance to accomplish when either system is used.

## OVERVIEW OF DRE w/ VVPT

While DREs w/ VVPT provide the accessibility benefits of a computer-based system, the voter must be able to read (or hear) the contents of the VVPT to verify her selections prior to casting her vote. For a voter with limited vision, the VVPT cannot be easily printed in a large-font for two principle reasons. First, in certain models, a VVPT prints into a hard case of a fixed size that may not accommodate a VVPT made larger by a larger font size. Second, ballots printed in a large-font by machines like the ones once manufactured by Accupoll, which printed out the VVPT on loose paper from an inkjet printer are, by definition, longer than other ballots. This may sacrifice the privacy of the voter's ballot selections because the large-font ballot's length would render it immediately distinguishable from other ballots.[157] For these reasons, voters with visual impairments may benefit from reviewing the VVPT via audio or on an enhanced electronic visual display so as to avoid the pitfalls of a large-print ballot.

As discussed below, technologies are just now being made available to allow blind voters to read such VVPTs by translating their text into audio. In the spring of 2005, Accupoll released its version of a barcode scanner that was mounted beside the DRE, read the VVPT barcode produced by the printer attached to the Accupoll DRE, and translated it into audio.[158] According to its representatives, Sequoia plans to release a similar mechanism early in 2006.[159] Scanning technology for VVPTs is still in its nascent development phase; it will be several years before thorough usability testing determines the efficacy of these scanners and their technology is fine-tuned.

## ANALYSIS OF DRE w/ VVPT

### 1. Can the system be physically adjusted to meet a voter's access needs?

To voters with disabilities that do not relate to their vision, DREs w/ VVPT provide essentially the same physical adjustability as DREs, discussed already. It is important to note, however, that if the paper record (*i.e.*, the VVPT) must be read behind a transparent cover as in most models, the position of that paper often cannot be changed. A voter with a narrow field of vision may need to reposition herself to see the paper record, placing the computer screen and possibly the controls out of reach for a time.

### 2. Does the system allow voters to adjust the visual presentation of information contained in the ballot or in voting instructions?

As with physical adjustments, DREs w/ VVPT systems can be adjusted just as DRE systems, except in that portion of the voting process that involves verification by the voter of her ballot. In all models, the print on the VVPT record is of a fixed size and appearance and is not subject to modification by the voter at any time. One system, Accupoll's AVS 1000, used to print the voter's selections on a full-sized sheet of paper (rather than a small strip) that a voter could handle and bring closer to her face.[160]

VVPT systems manufactured by Diebold, and ones once manufactured by Accupoll, offer an additional display option that may be helpful to voters with cognitive or learning disabilities. In those systems, the ballot screen and the VVPT are displayed simultaneously on a DRE's screen to allow for a side-by-side visual comparison of the two images, thereby simplifying verification for voters who have difficulties reading rows of information on a printed page.

### 3. Does the system allow voters to adjust the audio presentation of information contained in the ballot or in voting instructions?

Last spring, Accupoll introduced an electronic scanner that, according to company representatives, could read back the text of a VVPT to a voter.[161] Voters could adjust the speed and volume of the Accupoll scanner's playback. The elec-

tronic scanner rested next to a DRE. Each VVPT printed by the Accupoll DRE contained a barcode of the voter's selections, as well as a text version of those selections. A voter thus had to grasp the VVPT and swipe it under the scanner to verify her vote. Accupoll asserted that given the proximity of the scanner to the voting machine, blind voters should have had no trouble detecting the existence of a scanner with their hands and successfully completing the swipe. In theory, the only voters who would not have been able to verify their votes without assistance would have been voters with both physical and visual impairments. As of now, the barcode scanners once offered by Accupoll and promised by Sequoia are the only means for a voter to hear, rather than see, the contents of their VVPTs. Of course, only rigorous usability testing will be able to verify these predictions.

**4. Does the system provide an audio output/tactile input alternative access option to meet the needs of individuals with visual impairments or other difficulties reading?**

Every DRE w/ VVPT can be outfitted with an ATI. If a voter must take action in response to reviewing a VVPT, she can do so by using such an ATI.

**5. Does the system provide controls suitable for voters with limited fine motor skills?**

As long as voters have the visual facility to see a ballot and are provided with an ATI, DREs w/ VVPTs are fully accessible to such voters.

**6. Does the system allow simultaneous use of audio and visual outputs, in other words, for a voter to see and hear a ballot at the same time?**

DREs w/ VVPT allow the voter to see and hear the selections simultaneously during the initial phase of the voting process. Once the voter reaches the point at which she must verify her vote by reviewing the VVPT, however, the audio options are limited. As noted already, Accupoll offers audio rendering of VVPTs, and Sequoia might soon follow suit.

**7. Does the system allow simultaneous use of visual displays and tactile input controls?**

As long as a DRE w/ VVPT includes a set of auxiliary tactile controls, and the controls are programmed to input responses during the VVPT review process, VVPT systems can facilitate the simultaneous use of visual displays and tactile input controls.

**8. Can a voter choose and change accessibility and language options independently without the assistance of a poll worker?**

For DREs w/ VVPT, features selected for the initial computer-based portion of the voting process (*e.g.,* large-print or language options as well as audio options)

are not carried over into the voter's verification of the paper record. In the latter stage of the process, as discussed already, the only accessibility feature that has been on the market and may be in the future is a barcode reader that translates the paper record's contents into audio speech for verification.

VVPT could also encroach on the privacy of those voters who choose a language other than English to vote. In order for a voter to verify her ballot, the paper trail may need to be produced in her language of choice. This would reveal a special language choice on the printout – names of races would not be printed in English – and if the selection of a language other than English is rare in a particular precinct, a voter's privacy could be compromised should officials review ballots during a recount. Election officials could request that machines be configured to print every VVPT with labels written in both English and all other available languages, but this could require a sharp increase in paper use and cost and may be infeasible for other reasons. To date, no company has pre-programmed a machine to do so.

### 9. Is the system's audit function accessible to all voters?

Any voter that can read a VVPT is likely able to verify the accuracy of its text. As noted above, voters with visual impairments may require an enhanced visual display or audio rendering of their VVPTs in order to verify them. Ideally, enhanced visual and audio renderings of VVPTs would be derived from the same written text available to sighted voters. The only audio scanner once available for VVPTs, Accupoll's, read a barcode, not printed text.[162] It is possible that the barcode, rather than the text, could be counted as the official ballot in the event of a recount. In states where this proves true, voters with visual impairments who use a scanner like Accupoll's will avoid verifying selections that do not reflect the ballot of record in an election.

*OCR fonts are standard monospaced fonts designed for "optical character recognition" on electronic devices, such as scanners.*

Accessibility experts have suggested two alternatives to Accupoll's barcode scanner. First, certain scanners can read text printed in OCR fonts, and these scanners could prove helpful in reading VVPTs to voters. Scanners understand each letter, convert letters into words, and create a spoken version of a written word. VVPT printers could be programmed to use OCR fonts – indeed Accupoll's printers once did – and OCR scanners could be provided.[163] Second, some printers can read the words they produce, and VVPTs could be outfitted with such printers. Printers take note of each character they write and can sound out those characters into words. The accuracy of these audio renderings improves when there are limited options for what a word could be, such as a when a printer is choosing between two candidates in a race.[164]

## TELEPHONE-BASED SYSTEMS

In telephone-based voting systems, voters use a touchtone phone to dial a phone number that connects voters to an audio ballot. Voters press specific telephone keys to indicate their selections, and the system's software interprets the tones of those keys to record choices.[165] Telephone-based systems can be designed in two ways. In one scenario, states can configure their Vote-by-Phone lines to accept calls from any phone so that voters can cast ballots from home using their own equipment. Alternatively, states can limit incoming calls to a discrete set of phones housed at polling places. In this case, voters must travel to the polls to vote and use phones provided by the state. Unless carefully designed, these telephones can be largely inaccessible to voters with disabilities.

The only existent Vote-by-Phone systems, New Hampshire's and Vermont's, follow the latter model.[166] The great accessibility promise of Vote-by-Phone systems, however, lies in the possibility of allowing voters to vote from home on Election Day. At home, voters could use customized phones already configured with any special keypads or other features they might need. Perhaps most importantly, voting from home would save voters from traveling to a polling place. Many disabled voters cannot drive and could escape the cumbersome task of arranging for transportation on Election Day if they could vote from home. In addition, if all voters voted by telephone, states would not need to invest in rendering old polling places accessible to voters in wheelchairs. Thus, when combined with a Vote-by-Mail system for voters with hearing impairments, Vote-by-Phone systems could level the playing field by giving all voters the same remote voting experience.

Unfortunately, all telephone-based systems present significant barriers to voters with hearing impairments. First, the voter's ability to vote by phone depends upon the quality and nature of their adaptive equipment that facilitates full use of the telephone. Although many voters with hearing impairments possess such technology, many voters do not. In theory, jurisdictions using Vote-by-Phone systems that require voters to vote from home could obtain Text Telephones ("TTYs" or "TDDs") to connect with voters that have TTYs in their homes.[167] Only a small proportion of voters who have trouble hearing have access to TTYs, however, and Vote-by-Phone systems would need to be used in conjunction with Vote-by-Mail systems to accommodate many of these voters.

At present, Vote-by-Phone systems do not offer TTY-capabilities as an option on their voting systems.[168] For now, Inspire's Vote-by-Phone system thus comes with "a full-featured Election Management System (EMS) which enables the jurisdiction to configure and print blank paper ballots. These blank ballots could be mailed to, or made available at the polling sites for, those who are deaf and cannot use the telephone."[169] This option may not, however, aid those voters with sight and hearing difficulties.

Second, while Vote-by-Phone systems may provide significant accessibility benefits to blind voters accustomed to responding to audio output using a standard phone keypad, this mechanism may prove cumbersome and unfamiliar for other voters with other accessibility needs: older voters who have vision impairments and are also hard of hearing may not be able to navigate a phone system with ease. Voters with limited mobility may not be able to use the telephone keypad unless it is specially designed for such voters.

## ANALYSIS OF TELEPHONE-BASED SYSTEMS

### 1. Can the system be physically adjusted to meet a voter's access needs?

Standard telephones have a fixed cord length or range of operation, fixed keypad configuration, and fixed keypad size. If states insist that voters use telephones provided at a polling place, they may not be physically adjustable unless auxiliary features are provided. If voters cast ballots from their homes, however, they can use their personal phones. In all likelihood, these telephones will already be configured to accommodate the voter's needs and would not require physical adjustments.

### 2. Does the system allow voters to adjust the visual presentation of information contained in the ballot or in voting instructions?

All telephone-based systems use an audio, not a visual, ballot.

### 3. Does the system allow voters to adjust the audio presentation of information contained in the ballot or in voting instructions?

Although existent Vote-by-Phone systems in Vermont and New Hampshire do not allow voters to adjust the ballot's volume and speed, designers could program audio ballots to do so. In addition, many phones allow users to adjust a receiver's volume levels.

### 4. Does the system provide an audio output/tactile input alternative access option to meet the needs of individuals with visual impairments or other difficulties reading?

All Vote-by-Phone systems transmit information in audio form and ask voters to input information using tactilely discernible controls. However, Vote-by-Phone systems allow voters to access and enter information in only one way. Voters must enter their selections using a standard telephone keypad.[170] According to representatives of IVS, makers of Vermont's Vote-by-Phone system, if a voter cannot use a standard telephone for some reason, no alternative system exists for inputting ballot information using telephones.[171]

### 5. Does the system provide controls suitable for voters with limited fine motor skills?

A Vote-by-Phone system could be designed in two ways. In one scenario, a voter casts her ballots from home using her personal phone. In this case, the interface for a phone system is, by definition, the voter's own equipment and should be accessible to her.

In a second scenario, currently in practice in Vermont, the voter uses a phone to cast the ballot at a polling station where phones have been provided. Many voters with limited motor skills need a specially designed phone with an interface that is more accessible than a standard 12-key keypad. Indeed, these voters may need telephones to have an alternative switch input available or telephone end units adapted to their particular needs. As long a voter can access the unit, any adaptive technology which is able to replicate the tones of a keypad should be able to operate the Vote-by-Phone system. According to IVS, some of these adaptive technologies cannot meet this requirement, however, because they do not replicate the "distinct sounds generated by the telephone when its buttons are pressed."[172]

### 6. Does the system allow simultaneous use of audio and visual outputs, in other words, for a voter to see and hear a ballot at the same time?

Telephone-based systems cannot currently provide such a feature.

### 7. Does the system allow simultaneous use of visual displays and tactile input controls?

Telephone-based systems cannot currently provide such a feature.

### 8. Can a voter choose accessibility and language options independently without the assistance of a poll worker?

Vote-by-Phone systems have a limited range of accessibility options because they do not have a visual display and are only as accessible as the telephone system used by the voter. As discussed already, this can be prohibitive for voters with hearing impairments who must, in many cases, vote by mail. Nevertheless, these systems do protect the privacy and independence of those voters who can use the telephone through assistive devices or other means.

Like a computer interface, language options can be made a part of the initial steps of the voting process in telephone-based systems, allowing independent and private selection. Election officials should ask that this flexibility be implemented during initial ballot design.

### 9. Is the system's audit function accessible to all voters?

Vote-by-Phone systems produce a paper ballot, and auditing this ballot presents many of the same accessibility concerns as VVPTs. Once a voter has finished entering her choices, the system prints a marked paper ballot either to a central location, such as the Secretary of State's office, or at the precinct itself. This paper ballot is treated as the ballot of record.[173]

In the central location scenario, the voter cannot see her marked ballot. However, ballots are printed with a barcode that contains a voter's selections. This barcode can be scanned as it prints at the central office, translated into an audio ballot, and read back to the voter over the telephone. The voter can either reject or accept her ballot after hearing the barcode's contents. In jurisdictions where paper ballots, not barcodes, are the ballot of record, voters would review a proxy for a ballot, rather than the physical text that would be counted in an election.

By contrast, when ballots are printed at precincts, sighted voters can read the text printed on their ballots and verify its accuracy. Like with barcode scanners used with VVPTs, voters with vision impairments must have the visual and motor facility to use a barcode scanner to translate their ballots into an audio recording.

## KEY FINDINGS

Our report reached several conclusions about the accessibility of each system:

### COMPUTER-BASED SYSTEMS: DRES AND BMDS

- Accessibility of Computer-Based Systems: Because computer-based interfaces allow voters to tailor a range of features to their individual needs instantly and without assistance from another person, DREs and BMDs offer the greatest accessibility to voters with disabilities, particularly those with visual impairments.

- Audio and Enhanced Visual Display Capabilities for Voters with Visual Impairments: Unlike paper-based voting systems that do not provide any means for voters to hear rather than see instructions or ballot information, most DREs and BMDs allow voters to hear such information through headphones and to adjust the volume and rate of the audio output. In addition, several systems provide digitized (*i.e.*, real recorded human voice), rather than computer-synthesized, speech, and use different voices for instructions and ballot selections to expedite comprehension and thus the voting process itself. For voters with mild vision impairments who might not need an audio ballot, computer interfaces provide an enhanced visual display that uses bigger and bolder text.

- Alternative Input Devices for Voters with Motor/Coordination Impairments: Navigation of computer screens often requires that voters use controls that require hand-eye-coordination – a touch-screen or a mouse – to select their choices. For voters without the use of their hands or with severe motor impediments, a touch-screen cannot be used to make selections at all. In both cases, there must be an alternative input control available. The most popular computer-based systems already provide tactilely discernable input controls, often as part of the Audio Tactile Interface designed for voters who cannot see. Frequently these tactile controls can be used by individuals with mobility and coordination disabilities so long as the visual display remains active when those controls are engaged. For those voters who cannot use their hands at all to input selections, certain machines include a "dual switch input option," a jack for a voter to insert their own dual switch input device. Voters can, for example, attach a sip-and-puff device, which allows the voter to indicate choices by applying pressure to a straw or any other dual switch compatible with the scanning of the voting system.

## PAPER-BASED SYSTEMS

### PCOS

- Limited Flexibility to Meet Special Needs: First, with PCOS and Vote-by-Mail systems, the paper ballot itself must be printed prior to Election Day and thus cannot be adjusted to address the needs of a particular voter. In addition, despite magnifying lenses and other assistive devices provided by elections officials, voters with vision impairments still may have greater difficulties reading the paper ballot than they would reading a computer screen that allows fine contrast and size adjustments to be made. Paper-based systems do not have audio output or tactile input, and without some additional component added to the system, cannot provide it.

- Tactile Ballots for Voters with Visual Impairments: Certain small-scale innovations have been developed to help people with visual disabilities to mark paper ballots, including "tactile ballots." However, many voters with visual impairments still cannot review the marked ballot and must trust that it is marked correctly or obtain the assistance of another person to do so, with a consequent loss of independence and privacy.

- Inaccessible Auditory Instructions: If made available at all, auditory instructions for paper-based systems are presently produced by a cassette machine, rather than by a computer-based audio system. In practice, voters with visual impairments can neither change the speed of the audio nor skip forward or backward during the voting process. More importantly, such voters cannot review their ballots once they have been marked without another person reading the contents to them.

- Paper Ballots Inaccessible to Voters with Motor Coordination Impairments: Paper-based systems that require voters to mark the ballot manually present significant challenges to voters with either or both coordination and vision problems. Paper-based systems do not have "controls" to mark the ballot and instead require the voter to use a pen or pencil to mark it. Such systems are thus inaccessible to many voters with limited fine motor skills.

- Scanners Inaccessible to Many Voters with Visual, Mobility, or Motor Coordination Impairments: Systems that require voters to feed their marked ballots into a scanner present barriers not only for voters with impairments relating to vision, mobility, or coordination, but even to non-disabled voters who have coordination difficulties.

### Vote-by-Mail Systems

Vote-by-Mail systems provide unique benefits for voters with mobility impairments. These are the only systems that do not require travel to a polling place; the voter completes the voting process in her own physical environment with

more accessible writing surfaces or assistive devices tailored to that voter's specific needs. Nevertheless, voters with visual or motor coordination impairments still may be unable to vote independently using a paper ballot of any kind, including a mail-in ballot.

## HYBRID SYSTEMS

### DREs w/ VVPT

While DREs w/ VVPT provide the accessibility benefits of a computer-based system, voters with visual impairments are presently unable to review and verify the contents of the VVPT prior to casting their votes. Voting system manufacturers have just started to release scanners that read back the text of a VVPT to a voter, and those technologies are as yet unproven. In addition, despite assurances from the manufacturer that visually-impaired voters should have no trouble detecting the existence of a scanner with their hands and successfully scanning their VVPTs, voters who have both visual and motor impairments are likely to need assistance in using such technology to read their marked ballots. Of course, only rigorous usability testing will be able to verify these predictions.

### BMDs

BMDs greatly augment the accessibility of paper-based systems. Indeed, if the marking process were the end of the voting process, the use of paper ballots coupled with BMDs would present no greater barriers to voters with disabilities than DREs. Moreover, both the Automark and Populex BMDs allow visually-impaired voters to review the marks on their ballots on an enhanced visual display or in audio format. To activate these features, a voter needs only the visual and physical dexterity to use the scanner. For voters with limited vision or limited fine motor control, this may prove difficult and require assistance to accomplish.

## TELEPHONE-BASED SYSTEMS

Precinct-based Vote-by-Phone systems provide no greater accessibility than DREs or BMDs, and such systems may remain inaccessible to many voters. In particular, telephone-based systems may prove cumbersome for people with limited fine motor control and hearing impairments, especially those who have poor speech discrimination, or who rely on lip-reading, text, or other visual cues. To make a telephone voting system accessible for these individuals, audio signal enhancement and a text alternative would need to be available. Moreover, none of the currently available Vote-by-Phone systems allows the use of adaptive technologies to assist hearing-impaired voters, such as TTY phones. Finally, it is unclear to what extent other adaptive telephone end units could be used with current systems.

The future promise of Vote-by-Phone systems lies in the possibility of allowing Election Day voting from home, where voters could use customized phones already configured with any special keypads or other features they might need. Voting from home would save voters from traveling to a polling place. Thus, when combined with a Vote-by-Mail system for voters with hearing impairments, Vote-by-Phone systems could level the playing field by giving all voters the same remote voting experience. But the only existent Vote-by-Phone systems, New Hampshire's and Vermont's, require voters to vote at a polling place.

## RECOMMENDATIONS

This report provides a template of key questions and preliminary answers to assess the accessibility of the various types of voting systems. More significant testing must be performed to provide fuller answers. In such assessments, elections officials should keep in mind five general points:

- Assessments must take into account the specific needs of citizens with multiple disabilities. For example, solutions that solve barriers faced by voters with visual impairments by providing an audio ballot do not help a voter who is both blind and deaf.

- To determine accessibility, officials and advocates should examine each step a voting system requires a voter to perform, starting with ballot marking and ending with ballot submission. Systems that may provide enhanced accessibility features at one stage of the voting process may be inaccessible to the same voters at another stage in that process.

- Accessibility tests must take into account a full range of disabilities. When selecting participants for system tests, officials and advocates should include people with sensory disabilities (*e.g.,* vision and hearing impairments), people with physical disabilities (*e.g.,* spinal cord injuries and coordination difficulties), and people with cognitive disabilities (*e.g.,* learning disabilities and developmental disabilities). Given the rising number of older voters, officials should take pains to include older voters in their participant sample.

- All accessibility tests should be carried out with full ballots that reflect the complexity of ballots used in elections. A simplified ballot with only a few races or candidates may produce misleading results.

- Many features that ensure accessible voting are new to the market or still in development. As election officials purchase systems today, they should obtain contractual guarantees from vendors that vendors will retrofit their systems with new accessibility features as such technology becomes available, and that these adjustments will be made at little or no extra cost.

# ENDNOTES

[1] Help America Vote Act, 42 U.S.C. § 15481(a)(3)(A) (2002).

[2] Testimony of James C. Dickson, Election Assistance Commission, May 5, 2004 *available at* http://www.eac.gov/docs/EAC%20Testimony.pdf.

[3] *Id.*

[4] *Id.*

[5] Election Assistance Commission, *Voluntary Voting System Guidelines* at 4 (2005), *available at* http://www.eac.gov/VVSG%20Volume_II.pdf, [hereinafter EAC VVSG] (Last visited May 31, 2006).

[6] HAVA, 42 U.S.C. § 15481(a)(3)(D).

[7] HAVA, 42 U.S.C. § 15481(a)(3)(A).

[8] HAVA, 42 U.S.C. § 15481(a)(3)(B).

[9] HAVA, 42 U.S.C. § 15481(a)(3)(C).

[10] HAVA, 42 U.S.C. § 15481(a)(4).

[11] American with Disabilities Act, 42 U.S.C. § 12132 (1990). To establish a violation of Title II of the ADA, a plaintiff must demonstrate that: (1) he or she is a qualified individual with a disability; (2) he or she is being excluded from participation in, or being denied benefits of a public entity's services, programs, or activities, or is otherwise being discriminated against by a public entity; and (3) such exclusion, denial of benefits, or discrimination is by reason of his or her disability.

[12] Nondiscrimination Under Federal Grants and Programs, 29 U.S.C. § 794(a) (1998).

[13] Nondiscrimination on the Basis of Disability in State and Local Government Services, 28 C.F.R. § 35.151(a), (b) (1993).

[14] *American Association of People with Disabilities v. Hood*, 310 F. Supp. 2d 1226, 1235 (D. Fla. 2004).

[15] *Id.*

[16] *American Association of People with Disabilities v. Shelley*, 324 F. Supp. 2d 1120, 1126 (D. Ca. 2004).

[17] Federal Election Commission, *2002 Voting Systems Standards* at 1-2, *available at* http://www.eac.gov/election_resources/vss.html, [hereinafter 2002 VSS] (Last visited June 24, 2006).

[18] *Id.*, *supra* note 17 at §§ 2.10 – 2.12.

[19] *Id.*

[20] EAC VVSG, *supra* note 5 at 54.

[21] *Id.*, at D-4.

[22] *Id.*, at 54.

[23] *Id.*

[24] *Id.*, at 55.

[25] *Id.*, at 56.

[26] *Id.*, at 57.

[27] *Id.*, at 54.

[28] *Id.*, at 57.

[29] U.S. Census Bureau, *Profile of Selected Social Characteristics, Table DP-2: 2000, at* http://factfinder.census.gov/servlet/QTTable?_bm=y&-geo_id=D&-qr_name=DEC_2000_SF3_U_DP2&-ds_name=D&-_lang=en&-redoLog=false&-format=&-CONTEXT=qt (Last visited June 26, 2006).

[30] Gregg C. Vanderheiden, *Thirty-Something Million: Should They Be Exceptions?* 32 HUMAN FACTORS 383 (1990), *available at* http://park.org/Guests/Trace/pavilion/30_some.htm.

[31] National Center for Health Statistics, *Summary Health Statistics for U.S. Adults: National Health Interview Survey*, 222 VITAL AND HEALTH STATISTICS at 36, Table 11, *available at* http://www.cdc.gov/nchs/data/series/sr_10/sr10_222acc.pdf.

[32] *Id.*

[33] *Summary Health Statistics, supra* note 31 at p. 50, Table 18.

[34] U.S. Census Bureau, *Summary Table QT-P17: Ability to Speak English, available at* http://factfinder.census.gov/servlet/QTTable?_bm=y&-geo_id=01000US&-qr_name=DEC_2000_SF3_U_QTP17&-ds_name=DEC_2000_SF3_U&-_lang=en&-_sse=on (Last visited June 26, 2006).

[35] *Id.*

[36] Theofanos, M. F. and Redish, J. C., 2005. *"Helping Low-Vision and Other Users with Web Sites that Meet Their Needs: Is One Site for All Feasible?"* 52 SOCIETY FOR TECHNICAL COMMUNICATION at 9 (Feb. 2005) *available at* http://www.ingentaconnect.com/content/stc/tc.

[37] Indeed, the Trace Research and Development Center at the University of Wisconsin has suggested that "by extending and enhancing the usability of mainstream voting machines it may be possible to address the needs of as much as 99% of voters." Gregg C. Vanderheiden, *Using Extended and Enhanced Usability to Provide Access to Mainstream Electronic Voting Machines,* 10 INFORMATION TECHNOLOGY AND DISABILITIES (Dec. 2004), *available at* http://trace.wisc.edu/docs/2005-EEU-voting/index.htm.

[38] 2002 VSS, *supra* note 17.

[39] U.S. Access Board, *Section 508 Homepage: Electronic and Information Technology, at* http://www.access-board.gov/508.htm (Last visited June 26, 2006).

[40] EAC VVSG, *supra* note 5.

[41] Subpart C – Functional Performance Criteria
1194.31 Functional performance criteria.

(a) At least one mode of operation and information retrieval that does not require user vision shall be provided, or support for assistive technology used by people who are blind or visually impaired shall be provided.

(b) At least one mode of operation and information retrieval that does not require visual acuity greater than 20/70 shall be provided in audio and enlarged print output working together or independently, or support for assistive technology used by people who are visually impaired shall be provided.

(c) At least one mode of operation and information retrieval that does not require user hearing shall be provided, or support for assistive technology used by people who are deaf or hard of hearing shall be provided.

(d) Where audio information is important for the use of a product, at least one mode of operation and information retrieval shall be provided in an enhanced auditory fashion, or support for assistive hearing devices shall be provided.

(e) At least one mode of operation and information retrieval that does not require user speech shall be provided, or support for assistive technology used by people with disabilities shall be provided.

(f) At least one mode of operation and information retrieval that does not require fine motor control or simultaneous actions and that is operable with limited reach and strength shall be provided.

[42] EAC VVSG, *supra* note 5, at § 3.2.2.1.f.

[43] Email from Dave Alampi, Avante International Technology, Inc., (Jan. 11, 2006) (on file with the Brennan Center).

[44] Email from Michelle Shafer, Vice President of Communications and External Affairs, Sequoia Voting Systems, (Jan. 23, 2006) (on file with the Brennan Center).

[45] Email from Pat Gorman, Vice President of Operations and Deployment, Accupoll Inc., (Jan. 5, 2006) (on file with the Brennan Center). (Note: Accupoll Inc. filed for Chapter 7 bankruptcy on January 30, 2006. To date, no company has bought the rights to their technologies.).

[46] *Id.*

[47] Email from Dave Alampi, *supra* note 43.

[48] Email from Pat Gorman, *supra* note 45.

[49] The VVSG recommend that the size and weight of the system allow for portability and curbside voting. By the standard set out in the guidelines, the DRE models manufactured by Sequoia, Diebold, Hart and ES&S are all portable for curbside voting.

[50] Telephone Interview with Phillip Braithewaite, Vice President of Sales and Marketing, Hart Intercivic, (Jan. 18, 2006).

[51] Email from Rob Palmer, Director of Marketing and Communications, Election Systems and Software, (Jan. 16, 2006).

[52] Email from David Bear, Spokesperson, Diebold Election Systems, (Jan. 16, 2006).

[53] EAC VVSG, *supra* note 5, at §§ 3.2.2.1(b)-(d).

[54] Email from Michelle Shafer, *supra* note 44.

[55] Email from David Bear, *supra* note 52.

[56] Telephone Interview with Phillip Braithewaite, *supra* note 50.

[57] Email from Pat Gorman, *supra* note 45.

[58] *Id.*

[59] Email from Dave Alampi, *supra* note 43.

[60] Email from Michelle Shafer, *supra* note 44.

[61] Email from Rob Palmer, *supra* note 51.

[62] Email from David Bear, *supra* note 52.

[63] Telephone Interview with Phillip Braithewaite, *supra* note 50.

[64] Email from Pat Gorman, *supra* note 45.

[65] Email from Dave Alampi, *supra* note 43.

[66] Email from David Bear, *supra* note 52.

[67] Email from Michelle Shafer, *supra* note 44.

[68] Telephone Interview with Phillip Braithewaite, *supra* note 50.

[69] Email from Rob Palmer, *supra* note 51.

[70] EAC VVSG, *supra* note 5, at 58.

[71] Email from Michelle Shafer, *supra* note 44.

[72] Email from David Bear, *supra* note 52.

[73] Telephone Interview with Phillip Braithewaite, *supra* note 50.

[74] Email from Rob Palmer, *supra* note 51.

[75] Email from Dave Alampi, *supra* note 43.

[76] Email from Pat Gorman, *supra* note 45.

[77] In March of 2003, Manhattan Borough President C. Virginia Fields and the Center for Independence of the Disabled in New York asked 130 disabled voters to use eight different DREs and comment on the machine's accessibility. According to the report, "testers commented that computer generated voices were difficult to understand, while no tester cited difficulty understanding the human voice ballots." Office of the President of the Borough of Manhattan, *Voting Technology for People with Disabilities* at iii (April 3, 2003) *available at* http://www.eff.org/Activism/E-voting/Benavidez/20040518-benavidez-Amicus-Exh_C.pdf.

[78] Email from Michelle Shafer, *supra* note 44.

[79] Email from David Bear, *supra* note 52.

[80] Email from Pat Gorman, *supra* note 45.

[81] Telephone Interview with Phillip Braithewaite, *supra* note 50.

[82] Email from Rob Palmer, *supra* note 51.

[83] *See* EAC VVSG, *supra* note 5, at § 3.2.2.2(c) ix.

[84] Email from Dave Alampi, *supra* note 43.

[85] Email from Michelle Shafer, *supra* note 44.

[86] Email from David Bear, *supra* note 52.

[87] Email from Gregg Vanderheiden, Feb. 28, 2006 (on file with the Brennan Center).

[88] Email from Dave Alampi, *supra* note 43.

[89] Email from Michelle Shafer, *supra* note 44.

[90] Email from David Bear, *supra* note 52.

[91] Email from Pat Gorman, *supra* note 45.

[92] Telephone Interview with Phillip Braithewaite, *supra* note 50.

[93] Email from Rob Palmer, *supra* note 51.

[94] Email from Dave Alampi, *supra* note 43.

[95] Email from Michelle Shafer, *supra* note 44.

[96] Email from David Bear, *supra* note 52.

[97] Email from Pat Gorman, *supra* note 45.

[98] Telephone Interview with Phillip Braithewaite, *supra* note 50.

[99] Email from Rob Palmer, *supra* note 51.

100 *See* EAC VVSG, *supra* note 5, at §§ 3.2.2.2 (b)-(c).

101 According to a 2004 report by VotersUnite, for example, "the Diebold speech quality and response time were so poor that elderly voters and others with hearing problems would have serious difficulties understanding the speech of the systems." Similarly, in a letter to the registrar of voters of Santa Clara County, members of the Silicon Valley Council of the Blind criticized Sequoia's DRE voting machines, citing poor sound quality, delayed response time, and awkwardly-positioned Braille. The VotersUnite report also cited complaints that Avante's synthetic text-to-speech system was difficult for many users to understand. Voters Unite!, *Mythbreakers: Facts About Electronic Elections* at 59 *available at* http://www.votersunite.org/MB2.pdf (Last visited June 26, 2006).

102 Telephone Interview with Phillip Braithewaite, *supra* note 50.

103 Telephone Interview with Frank Wiebe, Chief Operating Officer, Accupoll Inc. (Oct. 19, 2005).

104 Email from Michelle Shafer, *supra* note 44.

105 Telephone Interview with Phillip Braithewaite, *supra* note 50.

106 Telephone Interview with Dave Alampi, Sales and Marketing at Avante (Oct. 21, 2005).

107 *See* EAC VVSG, *supra* note 5, at 56.

108 Email from Pat Gorman, *supra* note 45.

109 Telephone Interview with Rob Palmer, Director of Marketing and Communications, ES&S Voting System (Oct. 28, 2005).

110 Telephone Interview with David Bear, Spokesperson, Diebold Election Systems, (Oct. 25, 2005).

111 Telephone Interview with Phillip Braithewaite, *supra* note 50.

112 Telephone Interview with Alfie Charles, Media Relations, Sequoia Voting Systems (Oct. 18, 2005).

113 In its default setting, the eSlate requires all voters to use a standard set of tactilely discernible controls to input selections while viewing a visual ballot.

114 Telephone Interview with David Bear, *supra* note 110.

115 Email from Pat Gorman, *supra* note 45.

116 Telephone Interview with Alfie Charles, *supra* note 112.

117 Email from Pat Gorman, *supra* note 45.

118 Email from Dave Alampi, *supra* note 43.

119 Email from David Bear, *supra* note 52.

120 Email from Rob Palmer, *supra* note 51.

121 Email from Michelle Shafer, *supra* note 44.

122 Email from Rob Palmer, *supra* note 51; Email from Pat Gorman, *supra* note 45; Email from Dave Alampi, *supra* note 43; Email from David Bear, *supra* note 52; Email from Michelle Shafer, *supra* note 44; Telephone Interview with Phillip Braithewaite, *supra* note 50.

123 According to experts, the case of magnifying lenses highlights the burden certain inflexible assistive devices can place on both election officials and the voter: Lenses are made in different strengths. Officials may need to match lenses to a voter's vision disability and any current glasses they are wearing. Once given to the voter, she must place the lens at an appropriate distance from her eyes and have the facility and coordination to adjust the lens' placement as she reads.

[124] *See*, for example, Rhode Island's accessible voting options at *Guidelines for Braille and Tactile Ballots, available at* http://www.sec.state.ri.us/elections/voting/blindordisabledvoters/BrailleTactile BallotGuidelines.html (Last visited June 20, 2006).

[125] Email from Dave Alampi, *supra* note 43.

[126] Telephone Interview with David Bear, *supra* note 110.

[127] See a photo of the Sequoia scanner *at* http://www.sequoiavote.com/photo.php?photo= InsightFrontView.jpg &title=Insight%20Front%20View.

[128] Telephone Interview with Rob Palmer, Director of Marketing and Communications at Election Systems and Software (Oct. 28, 2005).

[129] In Oregon, for example, where Vote-by-Mail systems have been in use since 1998, it is often difficult for voters with visual impairments to vote privately and independently. According to a 2002 speech by Oregon's Secretary of State Bill Bradbury to the Association of the Bar of the City of New York, the counties' election offices send bipartisan teams to the homes of voters with visual impairments to provide assistance with the Vote-by-Mail process. As of 2002, one county offered ballots in Braille and thirty-five counties offered both the Instruction Pamphlet and ballot on audiotape. However, sending in a team to assist these voters deprives them of their ability to vote privately. At the time of the speech, Secretary Bradbury stated that Oregon was looking for ways to solve these privacy issues: "Instead of sending a team to assist a voter, we could send a person and something as small as a Palm Pilot. The voter could put on earphones and record their ballot electronically, rather than having to tell election officials how they want to vote." Secretary Bradbury's speech is available at http://www.sos.state.or.us/executive/speeches/111802.html.

[130] Of course, experts note, not all voters with vision limitations are comfortable, or even able, to use an audio ballot. They may simply be unfamiliar with this kind of technology, or may have difficulty processing instructions from an audio recording.

[131] For a full description of the tactile ballot, *see* the International Frontier for Election Systems' web site *at* http://www.electionaccess.org/Bp/Ballot_Templates.htm (Last visited June 26, 2006).

[132] *See* Elections and Civics Division of the Office of the Secretary of State of Rhode Island, *Am I Eligible to Vote by Using Braille or Tactile Ballot?, at* http://www.sec.state.ri.us/elections/faq/ braille-or-tactile.html (last visited June 26, 2006).

[133] State of Oregon Elections Division, *Requesting a Replacement Ballot, at* http://www.uhava vote.org/elect_q_a/ ballots/ballot_rep.html (Last visited June 26, 2006).

[134] Email from Rob Palmer, *supra* note 51.

[135] *See* Populex Digital Paper Ballot System Overview *at* http://www.populex.com/ DPB_Overview.htm.

[136] Email from Rob Palmer, *supra* note 51; Email from Sandy Morganstein, President and Founder, Populex Corporation (Jan. 13, 2006).

[137] Telephone Interview with Liz Miller, Public Affairs Liason, Populex Corporation (Oct. 24, 2005); Email from Rob Palmer, *supra* note 51.

[138] Email from Sandy Morganstein, *supra* note 136.

[139] Email from Rob Palmer, *supra* note 51.

[140] A photo of the Automark unit is available at http://www.automarkts.com (Last visited June 20, 2006). Email from Sandy Morganstein, *supra* note 136.

[141] Telephone Interview with Rob Palmer, *supra* note 128; Email from Sandy Morganstein, *supra* note 136.

142 Email from Rob Palmer, *supra* note 51; Email from Sandy Morganstein, *supra* note 136.

143 *Id.*

144 *Id.*

145 Email from Rob Palmer, *supra* note 51.

146 Email from Sandy Morganstein, *supra* note 136.

147 Email from Rob Palmer, *supra* note 51.

148 Telephone Interview with Richard Vogel, President, Vogue Election Systems (Nov. 1, 2005); Email from Rob Palmer, *supra* note 51; Email from Sandy Morganstein, *supra* note 136.

149 Telephone Interview with Richard Vogel, *supra* note 148; Email from Rob Palmer, *supra* note 51.

150 Email from Rob Palmer, *supra* note 51; Email from Sandy Morganstein, *supra* note 136.

151 Telephone Interview with Rob Palmer, *supra* note 128.

152 Email from Sandy Morganstein, *supra* note 136.

153 Email Interview with Richard Vogel, President, Vogue Election Systems (Jan. 11, 2006).

154 Telephone Interview with Richard Vogel, *supra* note 148; Email from Rob Palmer, *supra* note 51.

155 Email from Rob Palmer, *supra* note 51.

156 Telephone Interview with Liz Miller, *supra* note 137.

157 Telephone Interview with Frank Wiebe, *supra* note 103.

158 *Id.*

159 Telephone Interview with Alfie Charles, *supra* note 112.

160 From product demo, *available at* http://www.accupoll.com/Presentation/10/.

161 Telephone Interview with Frank Wiebe, *supra* note 103.

162 Accupoll maintains that its barcode scanner renders a VVPT accessible to blind voters. In Accupoll systems, a VVPT's text is derived from the barcode printed on it, not from selections stored in the memory card inside a DRE. Thus, according to Accupoll representatives, all voters are treated equally because sighted voters read the barcode's contents and voters with visual limitations hear it. Telephone Interview with Frank Wiebe, *supra* note 103.

163 Telephone Interview with Gregg C, Vanderheiden, Director, Trace Center, University of Wisconsin-Madison (Nov. 9, 2005).

164 *Id.*

165 Telephone Interview with Gail Hart, Vice President of Communications and External Affairs, IVS LLC (Nov. 3, 2005). *See also* the "Vote by Phone" section on the IVS website *available at* http://www.ivsllc.com.

166 For a description of New Hampshire's vote-by-phone system, *see* New Hampshire Public Radio, *State Tests New Accessible Voting Machines* (March 21, 2006) *at* http://www.nhpr.org/node/10439. For a description of Vermont's system *see* Burlington Free Press (Aug. 11, 2005) *at* http://www.burlingtonfreepress.com/apps/pbcs.dll/article?AID=/ 20050811/NEWS01/ 508110314/1009&theme.

[167] In the mid-1990s, there were over 4 million TTY users, 3 million of whom had some sort of hearing impairment and 1 million of whom had some sort of speech impediment. However, this is only 13% of the 30.8 million adults who reported having trouble hearing. Michigan State University, *What is a TTY, at* http://www.captions.com/tty.html (Last visited June 26, 2006).

[168] Email from Gail Hart, Vice President of Communications and External Affairs, IVS LLC (Jan. 18, 2006).

[169] *See* IVS' website *at* http://www.ivsllc.com (Last visited June 26, 2006).

[170] Email from Gail Hart, *supra* note 168.

[171] Telephone Interview with Gail Hart, *supra* note 165.

[172] *See* the "Vote by Phone" section of IVS' website *at* http://www.ivsllc.com.

[173] Email from Gail Hart, *supra* note 168.

# USABILITY

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## INTRODUCTION

The performance of a voting system is measured in part by its success in allowing a voter to cast a valid ballot that reflects her intended selections without undue delays or burdens. This system quality is known as "usability."[1] Following several high-profile controversies in the last few elections – including, most notoriously, the 2000 controversy over the "butterfly ballot" in Palm Beach – voting system usability is a subject of utmost concern to both voters and election officials.

**Defining Usability.** In this chapter, we examine the usability of various voting systems and discuss several ways that election officials can maximize the usability of these systems. By maximizing the usability of a system, we mean ensuring, to as great a degree as possible, that voting systems: (a) effectively (correctly) record voters' intended selections, (b) complete the voting process in an efficient and timely manner, and (c) provide voters with confidence and satisfaction in the voting process.

**Analysis.** Our discussion of voting system usability proceeds in two stages.

- Effectiveness (or Correctness). We review original research conducted by Dr. David Kimball, which quantifies the extent to which current voting systems correctly record voters' intended selections, *i.e.,* the systems' "effectiveness." Specifically, Dr. Kimball looks at the residual vote rate for each major voting system in the 2004 presidential election. The "residual vote rate," the difference between the number of ballots cast and the number of valid votes cast in a particular contest, is viewed by many experts as the single best measure of the effectiveness of a voting system. Based on the research on voting system and general usability standards, we extract four key findings about the effectiveness of various voting systems. The findings may be found on pages 10–11.

- Efficiency and Voter Confidence. We summarize the limited research available on the efficiency of and voter confidence in the various systems.

**Usability Principles.** From this work and other research into usability, we then identify a series of usability principles applicable to voting systems which elections officials and advocates should use to assess and improve the usability of voting systems in their jurisdictions. The principles may be found on pages 108–115.

**Usability Recommendations.** Finally, we provide recommendations to assist election officials in maximizing the usability of their voting systems in the areas of ballot design and system instructions. A full discussion of the recommendations may be found on pages 116–117. They are summarized below:

- Do not assume familiarity with technology.
- Conduct usability testing on proposed ballots before finalizing their design.
- Create plain language instructions and messages in both English and other languages commonly used in the jurisdiction.
- Locate instructions so they are not confusing or ignored.
- For both ballots and instructions, incorporate standard conventions used in product interfaces to communicate a particular type of information or message.
- Do not create ballots where candidates for the same office appear in multiple columns or on multiple pages.
- Use fill-in-the-oval ballots, not connect-the-arrow ballots, for optical scan systems.
- Ensure that ballot instructions make clear that voters should not cast both a write-in and normal vote.
- Provide mechanisms for recording and reviewing votes.
- Make clear when the voter has completed each step or task in the voting process.
- Eliminate extraneous information on ballots.
- Minimize the memory load on the voter by allowing her to review, rather than remember, each of her choices during the voting process.
- Ensure that the voting system plainly notifies the voter of her errors.
- Make it easy for voters to correct their errors.

## DEFINING USABILITY

Any usability benefits of a particular type of voting system may be eclipsed partially, if not entirely, by a poor ballot design or confusing instructions.

In December of 2005 the Election Assistance Commission ("EAC") released the Voluntary Voting Systems Guidelines ("VVSG 2005"), which include the first set of usability requirements applicable to voting systems in this country.[2] As part of this work, the National Institute of Standards and Technology ("NIST") has undertaken to develop a set of precise performance criteria and test protocols to measure the usability of specific voting systems.

A consensus among experts as to the definition of usability of voting systems has developed out of usability research in other areas of technology. The International Organization for Standardization ("ISO") defines usability as "the extent to which a product can be used by specified users to achieve specified goals with *effectiveness, efficiency* and *satisfaction* in a specified context of user."[3]

Both the draft voting systems of the Institute of Electrical and Electronics Engineers ("IEEE")[4] and the VVSG 2005[5] echo these standards, noting that usable voting systems will *effectively and correctly* record voters' intended choices, operate *efficiently*, and instill *confidence* in the voter that her choice was correctly recorded and that her privacy was assured.

Before reviewing the performance of the various voting systems under the usability guidelines, it should be noted that usability is affected not solely by the type of voting system at issue, but also by the ballot and instructions designed by the vendors or elections officials for a particular jurisdiction. Indeed, any usability benefits of a particular type of voting system may be eclipsed partially, if not entirely, by a poor ballot design or confusing instructions. For this reason, the recent public debate over the strengths and weaknesses of various voting systems may have unduly obscured the importance of what should occur to improve the voting process after elections officials have made their choice of system. Although we do not yet have sufficient data to prescribe a single "best" or "most usable" ballot design for each system, there is a substantial body of research on the usability of forms (both paper and electronic), instructions, and other signage that can be used as guidance. In addition, given the variations in local laws and practices, elections officials should conduct their own usability testing where possible on their chosen system to limit design flaws that lead to voter errors.

The failure of a voting system to protect against residual votes is likely to harm low-income and minority voters and their communities more severely than other communities.

# ANALYSIS

## EFFECTIVENESS (OR CORRECTNESS)

There are few published studies of usability testings that have compared the effectiveness of different voting systems in accurately recording voter intention in a controlled environment.

Absent such testing, one of the most revealing available measures of voting system effectiveness is what is referred to in the political science literature as the residual vote rate. The "residual vote rate" is the difference between the number of ballots cast and the number of valid votes cast in a particular contest. Residual votes thus occur as the result of undervotes (where voters intentionally or unintentionally record no selection) or overvotes (where voters select too many candidates, thus spoiling the ballot for that contest).[6] Exit polls and other election surveys indicate that slightly less than 1% of voters intentionally abstain from making a selection in presidential elections.[7] Thus, a residual vote rate significantly higher than 1% in a presidential election indicates the extent to which the voting system's design or the ballot's design has produced unintentional voter errors.

Significantly, several studies indicate that residual vote rates are higher in low-income and minority communities and, in addition, that improvements in voting equipment and ballot design produce substantial drops in residual vote rates in such communities.[8] As a result, the failure of a voting system to protect against residual votes is likely to harm low-income and minority voters and their communities more severely than other communities.

This section reviews research previously published by Dr. Kimball, and research that he is publishing here for the first time, on the residual vote rates for various voting systems in the 2004 elections.

### METHODOLOGY

For the most part, Dr. Kimball used a cross-sectional analysis to generate the research findings discussed below. In a cross-sectional analysis, a particular characteristic is compared across jurisdictions. Here, for a given election, residual vote rates are compared across jurisdictions using a multivariate statistical analysis to control for factors other than voting system (such as demographics, the level of competition in the election, and other features of the local electoral context). Because of the decentralized nature of election administration in the United States, local elections officials generally make their own decisions about purchasing voting technology, as well as designing and printing ballots. As a result, voting technology and ballot design vary from one jurisdiction to the next, often even within the same state. This report also reviews a smaller number of studies examining residual votes and voting technology over time to take advantage of local changes in voting equipment. Examining both types of studies allows a

difference-in-difference research design to provide a more rigorous estimate of the impact of voting technology.[9]

## RESIDUAL VOTE RATES

Table U1 summarizes the rates of residual votes for the relevant voting systems found by Dr. Kimball in the election results for president (2000 and 2004) and governor (2002):

TABLE U1

RESIDUAL VOTE RATES BY TYPE OF VOTING TECHNOLOGY

| Technology | Description | Residual Vote Rate In: 2000 | 2002 | 2004 |
|---|---|---|---|---|
| Full-face DRE | Candidates listed on a full-face computerized screen – voter pushes button next to chosen candidate. Machine records and counts votes. | 1.6% | 2.2% | 1.2% |
| Scrolling DRE | Candidates listed on a scrolling computer screen – voter touches screen next to chosen candidate. Machine records and counts votes. | — | 1.2% | 1.0% |
| Central-Count Optical Scan | Voter darkens an oval or arrow next to chosen candidate on paper ballot. Ballots counted by computer scanner at a central location. | 1.8% | 2.0% | 1.7% |
| Precinct Count Optical Scan | Voter darkens an oval or arrow next to chosen candidate on paper ballot. Ballots scanned at the precinct, allowing voter to find and fix errors. | 0.9% | 1.3% | 0.7% |
| Mixed | More than one voting method used. | 1.1% | 1.5% | 1.0% |
| Nationwide Residual Vote Rate | | 1.8% | 2.0% | 1.1% |

Based on 1755 counties analyzed in 2000,
1270 counties analyzed in 2002, and 2215 counties analyzed in 2004

### DIRECT RECORDING ELECTRONIC ("DRE") SYSTEMS

Full-face DRE systems produce higher residual vote rates (1.2%) than both scrolling DRE systems (1.0%) and precinct count optical scan ("PCOS") systems (0.7%). "Full-face" DRE systems employ a ballot that displays all of the offices and candidates on a single screen, rather than in consecutive, separate screens that the voter touches to select her preferred candidates. As shown in Table U2,

however, two scrolling DRE systems produced a residual vote rate of 0.7% – the same as the nationwide average rate for PCOS systems.

TABLE U2:

RESIDUAL VOTE RATES BY SCROLLING DRE BRAND
2004 PRESIDENTIAL ELECTION

| Brand of Voting Machine | Residual Vote Rate |
|---|---|
| UniLect Patriot (17 counties) | 6.8% |
| VTI VotWare (1 county) | 4.1% |
| Fidlar-Doubleday EV 2000 (8 counties) | 2.3% |
| Hart InterCivic eSlate (8 counties) | 1.8% |
| MicroVote Infinity (20 counties) | 1.6% |
| Advanced Voting Solutions WinVote (10 counties) | 1.1% |
| Diebold AccuVote-TSX (1 county) | 0.9% |
| Sequoia AVC Edge (24 counties) | 0.8% |
| ES&S iVotronic (54 counties) | 0.7% |
| Diebold AccuVote-TS (190 counties) | 0.7% |
| Sequoia DRE with VVPT (17 counties in Nevada) | 0.3% |
| Nationwide Scrolling DRE Residual Vote Rate | 1.0% |

Based on 353 counties using scrolling DREs in 2004

The performance of full-face and scrolling DRE systems diverges even more as the income level of the voters declines. Stated differently, relative to scrolling DRE systems, full-face DRE systems produced particularly high residual vote rates among voters with incomes of less than $25,000 in 2004. Similarly, full-face DREs tend to produce higher residual vote rates than scrolling DREs in counties with large Hispanic or African American populations. Indeed, only punch card systems produced a higher residual vote rate than full-face DREs in jurisdictions with a Hispanic population of over 30%. *See* Table U3.

While the residual vote rates produced by both scrolling and full-face DREs decrease slightly as the percentage of African American voters increases (1.0% to 0.8%), such rates *increase* significantly as the percentage of Hispanic voters increases beyond 30% of the population (0.9% to 1.4% for scrolling DREs). The reasons for these trends are not clear, but they suggest that additional analysis should be conducted by elections officials and vendors to determine whether and how DREs could be programmed to address the language needs of Spanish-speaking voters more effectively.

TABLE U3:

RACIAL AND ECONOMIC DISPARITY IN RESIDUAL VOTES BY VOTING TECHNOLOGY
2004 PRESIDENTIAL ELECTION

| Composition of County | Votomatic Punch Cards | Optical Scan Central | Optical Scan Precinct | Full-Face DRE | Scrolling DRE |
|---|---|---|---|---|---|
| **Racial/Ethnic** | | | | | |
| Less than 10% black | 1.8% | 1.5% | 0.8% | 1.3% | 1.0% |
| Between 10% and 30% black | 1.7% | 1.7% | 0.5% | 1.2% | 0.9% |
| Over 30% black | 2.4% | 4.1% | 0.9% | 1.3% | 0.8% |
| Less than 10% Hispanic | 1.8% | 1.7% | 0.6% | 1.1% | 1.0% |
| Between 10% and 30% Hispanic | 1.8% | 1.1% | 0.9% | 1.1% | 0.7% |
| Over 30% Hispanic | 2.4% | 1.9% | 1.2% | 2.0% | 1.4% |
| **Median Income** | | | | | |
| Less than $25,000 | 4.0% | 3.3% | 1.4% | 2.8% | 1.3% |
| Between $25,000 and $32,499 | 2.3% | 1.7% | 0.8% | 1.4% | 1.1% |
| Between $32,500 and $40,000 | 2.0% | 1.6% | 0.7% | 1.3% | 1.0% |
| Over $40,000 | 1.5% | 1.2% | 0.7% | 0.9% | 0.8% |

Based on 2402 counties analyzed in 2004

Researchers at the Institute for Social Research at the University of Michigan have released preliminary findings from usability testing they conducted on several DRE systems.[10] Their early findings suggest that specific model and ballot design features may lead to different incidences of voter error produced by different manufacturers' DREs. In a laboratory comparison between the Hart InterCivic eSlate and Diebold AccuVote-TS, for example, the authors found that the two manufacturers' approaches to providing the voter with an opportunity to review her selections before casting her vote produce different error rates.

Both machines present the voter with a two-page "review" screen prior to casting the vote. According to the researchers, the eSlate's "review" screen appears more distinct in both color and format from the earlier pages that the voter sees than does the AccuVote-TS review screen. In addition, if the eSlate voter activates the control to "cast" the ballot prior to reviewing both screens, that machine then shows the voter the second review screen rather than casting the ballot immediately. By contrast, the AccuVote-TS allows the voter to circumvent the review process midstream by touching the screen to "cast" her ballot.

The researchers who conducted this testing hypothesize that these two design differences may be responsible for a greater incidence of unintended voter errors from the AccuVote-TS DRE, as voters do not devote as much attention to review-

Preliminary findings demonstrate the critical importance of usability testing of specific models within a type of voting system to reduce unnecessary voter errors.

ing and correcting their selections.[11] Although preliminary in nature, such findings demonstrate the critical importance of usability testing of specific models within a type of voting system to reduce unnecessary voter errors. Although both of these systems are DREs, such differences in ballot design produce very different opportunities for voter error in each of the two machines.

### DRE SYSTEMS WITH VOTER-VERIFIED PAPER TRAILS ("VVPT")

Only one state, Nevada, used a DRE system w/ VVPT in the 2004 election. In addition, Nevada is the only state in the country that includes a "none of the above" option on the ballot for federal and statewide elections. This option reduces undervotes, regardless of the voting system being used, because it allows voters who wish to cast a protest vote to do so without registering a "lost" vote. Because no other states used comparable systems or ballot options, the data are too limited to draw any conclusions regarding residual vote rates. The 17 Nevada counties registered a miniscule residual vote rate of 0.3% in the 2004 elections, but this figure is not directly comparable to that produced by other jurisdictions with different ballot options.

### PRECINCT COUNT OPTICAL SCAN SYSTEMS

With the exception of Nevada's DRE system,[12] the specific voting systems that produced the lowest residual vote rate in the country in 2004 – both at 0.6% – were the AccuVote-OS and ES&S M100 precinct count optical scan systems. *See* Table U4. In addition, the nationwide average residual vote rate for PCOS systems was lower in 2004 than the average rate for either type of DRE system.

TABLE U4:

RESIDUAL VOTE RATES BY PRECINCT COUNT OPTICAL SCAN BRAND
2004 PRESIDENTIAL ELECTION

| Brand of Voting Machine | Residual Vote Rate |
|---|---|
| ES&S Optech 3P Eagle (220 counties) | 0.9% |
| ES&S M100 (102 counties) | 0.6% |
| Diebold AccuVote-OS (264 counties) | 0.6% |
| Nationwide PCOS Residual Vote Rate | 0.7% |

Based on 630 counties using PCOS in 2004

Unlike for scrolling DREs and central-count optical scan systems, residual vote rates for PCOS systems do not appear to correlate significantly with the percentage of African American voters within the jurisdiction. *See* Table U3. But residual vote rates for both PCOS and DRE systems increase significantly with the percentage of Hispanic voters. This conclusion suggests that neither PCOS nor

DRE systems succeed in eliminating the impact of voters' language needs on the extent of residual votes. When compared with other voting systems, however, PCOS systems and scrolling DREs appear most successful at minimizing the correlation between residual votes and the racial, ethnic, or economic composition of a county.

PCOS systems and scrolling DREs appear most successful at minimizing the correlation between residual votes and the racial, ethnic, or economic composition of a county.

Differences in ballot design for optical scan systems produce significant differences in residual vote rates. First and foremost, ballots that required voters to darken an oval produced a residual vote rate of 0.6% in the 2004 election, while those that required voters to connect an arrow with a line to a candidate produced a rate of 0.9%. *See* Table U5. Plainly, the former design is preferable to avoid spoiled ballots. In addition, other ballot design features have been found to affect error rates in optical scan systems.

TABLE U5:

RESIDUAL VOTES IN OPTICAL SCAN BALLOTS BY TYPE OF VOTING MARK
2004 PRESIDENTIAL ELECTION

| | Type of Mark | |
|---|---|---|
| Where Ballots Are Counted | Darken an Oval | Connect an Arrow |
| Precinct Count (641 counties) | 0.6% | 0.9% |
| Central Count (767 counties) | 1.4% | 2.3% |
| Nationwide Optical Scan Residual Vote Rate | 1.0% | |

A recent pilot study of ballots from 250 counties in five states identified seven design recommendations for paper-based optical scan ballots, many of which could apply to other voting systems as well.[13] These recommendations are listed later in this report along with the usabilty principles they support.

### VOTE-BY-MAIL SYSTEMS

At present, the state of Oregon is the only jurisdiction within the United States that uses a Vote-by-Mail system ("VBM") as its principal voting system. Accordingly, definitive conclusions about the residual vote rates of VBM systems must await additional studies of that state and of jurisdictions outside the United States, such as Great Britain. Studies of Oregon's experience indicate that the adoption of a statewide VBM system in 2000 had no substantial impact either on voter participation or residual vote rates in Oregon elections. For example, the residual vote rate in Oregon in the 1996 presidential election (before adoption of VBM) was 1.5%, while the residual vote rate in Oregon in 2000 was 1.6%.[14] These figures do suggest that VBM systems may produce significantly higher residual vote rates than either PCOS or scrolling DRE systems.

Although further research must be conducted to determine precise causes of this discrepancy, it may stem from the fact mail-in ballots are scanned and counted using the same technology as the centrally counted optical scan systems used in other jurisdictions. As shown in Table U1, the residual vote rate for such systems in the 2004 elections was 1.7%. By definition, such systems do not allow the voter to be notified of, or to correct, any under- or overvotes she may have unintentionally indicated on her ballot. Therefore, while VBM systems may have other benefits, these systems are not as effective in minimizing residual votes as DRE or PCOS systems.

*Typically, a BMD is an accessible computer-based voting system that produces a marked ballot. The ballot is marked as the result of voter interaction with visual or audio prompts. Some jurisdictions use BMDs instead of accessible DREs.*

### OTHER SYSTEMS

Unfortunately, no data are yet available concerning the actual residual vote rates for Ballot Marking Devices ("BMDs") or Vote-by-Phone systems because few of these systems have yet been used in elections in this country.

## LIMITS OF RESIDUAL VOTE RATE STUDIES

Measuring the residual vote rates of top-of-the-ticket races indicates how often voters interact with a particular voting system on Election Day in such manner as to produce an incorrect (or ineffective) vote that does not reflect their intended selections. But residual vote rates reflect only the frequency of voter errors; they do not provide any basis to determine the reason for the voter errors on a particular type of voting system. Moreover, few if any jurisdictions gather data concerning the number or nature of requests for assistance by voters on Election Day, how long it takes for voters to vote, or any other information that would help to assess the efficiency or confidence produced by particular voting systems. For this reason, election officials should consider ways to gather such information on Election Day in selected precincts in order to facilitate future improvements in voting system and ballot design. In the meantime, election results provide an important but limited way to assess the usability of a particular voting system.

## KEY FINDINGS

Key findings from the limited available research on the effectiveness of various voting technologies are as follows:

- With few exceptions, PCOS systems and scrolling DREs produce lower rates of residual votes than central-count optical scan, full-face DRE, or mixed voting systems.

- Residual vote rates are higher on DREs with a full-face ballot design than on scrolling DREs with a scrolling or consecutive screen format. The negative impact of full-face ballot design in terms of lost votes is even greater in low-income and minority communities than in other communities.

- PCOS systems produce significantly lower residual vote rates than central-count optical scan systems because the former systems allow the voter to correct certain of her errors prior to casting her ballot.

- VBM systems produce higher residual vote rates than PCOS or DRE systems. VBM systems are comparable in this regard to central-count optical scan systems, which employ the same technology and counting process. Like central-count optical scan systems, VBM systems provide no opportunity for the voter to be notified of, or to correct, any under- or overvotes on her ballot prior to its being counted.

## EFFICIENCY AND VOTER CONFIDENCE

The existing research concerning the time each system requires to complete the voting process, the burdens imposed upon voters, and the confidence each system inspires among voters remains extremely limited. We summarize that research below.

### DREs

Several studies of DREs since 2000 have provided an overview of potential usability concerns based on limited testing and expert reviews, but scholars have only recently started to conduct fuller usability tests with statistical and analytical significance.[15] In addition, two economists recently analyzed voter turnout in the State of Georgia in 2002 and found a positive relationship between the proportion of elderly voters and a decrease in voter turnout from 1998 levels; the authors hypothesize that this evidence suggests that elderly voters were "apprehensive" about the statewide change in voting technology to DREs.[16]

Dr. Frederick G. Conrad of the University of Michigan, and collaborators Paul Herrnson, Ben Bederson, Dick Niemi and Mike Traugott, have recently completed one of the first major usability tests on electronic voting systems other than vendor testing. They analyze the steps required to complete voting in a single election and suggest that certain DREs require substantially more actions by a voter – *i.e.*, touches to the screen, turns to a navigation wheel, *etc.* – to select a candidate or ballot measure than other DREs. Not surprisingly, they have found that more actions mean more time to complete the voting process, as well as lower voter satisfaction with the DRE in question. In particular, Hart InterCivic's eSlate required 3.92 actions per task and 10.56 minutes on average for a voter to complete the voting process while Diebold's AccuVote-TS required only 1.89 actions per task and only 4.68 minutes to complete the process. Out of the six systems analyzed, participants in that study indicated that they were most comfortable using the AccuVote-TS and least comfortable using the eSlate.[17]

The same research suggests, however, that design elements that decrease efficiency or voter confidence may actually increase the accuracy of voters' selections.

Usability testing may be most valuable in evaluating the performance of a system as a whole and in making clear the tradeoffs elections officials must consider.

For example, eSlate's approach to facilitating the voter's review of her selections prior to voting both adds time to the voting process and increases the likelihood that a voter will catch her errors and correct them prior to casting her ballot. Accordingly, usability testing may be most valuable not in eliminating any one problematic feature of a system, but instead in evaluating the performance of a system as a whole and in making clear the tradeoffs election officials must consider in selecting a system and in designing the ballot and instructions.

In a research project sponsored by the Brennan Center for Justice and conducted by MIT Professor Ted Selker, the authors conducted a one-day simulated election test at a YMCA regularly used as a polling place. The test compared the voting experiences of people with and without reading disabilities on full-faced voting machines and a standard screen-by-screen voting machine. Three machines were tested: one DRE with a full-face ballot (ES&S's V2000 LED); one DRE with a scrolling ballot design and an LCD display (ES&S's iVotronic LCD); and a prototype DRE with a full-face ballot displayed on a lever machine-sized, high-resolution screen (iVotronic LS Full Faced DRE). 48 of 96 participants had been previously diagnosed with a reading disability, and researchers attempted to catch undiagnosed reading disabilities by testing all participants prior to the voting simulation. The results have implications for all voters. Notably, voters with undiagnosed reading disabilities and voters with no disabilities had much higher rates of undervotes on full-faced machines than on scrolling voting machines. This population also had fewer errors on the commercial DRE than on full-faced voting machines. People who had been diagnosed with reading disabilities were able to compensate for their difficulties and had fewer than other participants on full-faced voting machines. All voters took more than 3 minutes to vote but all reading disabled people took longer to vote on the scrolling DRE than the full-faced DRE.[18] These conclusions confirm the evidence of higher incidence of "roll off" produced by full-face lever and DRE voting systems in real elections.[19]

### DRES w/ VVPT

Professor Selker and his team at MIT's Media Lab have attempted to assess the extent to which voters who use such machines actually review the VVPT prior to casting their votes. In their testing, the authors found that no VVPT users reported any errors during the voting process though two existed for each ballot they used. At the end of the voting process, testers asked VVPT users whether they believed any errors existed on their paper record even if they did not report them. Only 8% answered yes. In contrast, users of an audio-based verification system reported errors at higher rates. 14% of users reported errors during the voting process, and 85% of users told testers that they believed errors existed in the record although they did not all report them.[20] Additional research needs to be conducted to measure the efficiency of and voter confidence in these systems. But Dr. Selker's research suggests that VVPTs may present significant usability problems that can prevent voters from identifying errors readily.

## PRECINCT COUNT OPTICAL SCAN SYSTEMS

No available research has measured the efficiency of or voter confidence in optical scan systems. This is a significant gap in the literature that hampers sound comparisons between DREs and optical scan systems and also limit public scrutiny of ballot design in these systems.

## OTHER SYSTEMS

Unfortunately, no research is yet available that has measured the efficiency of or voter confidence in BMDs or Vote-by-Phone systems because few of these systems have yet been used in elections in this country. In addition, no studies have measured these variables for VBM systems, as used presently in Oregon.[21]

## USABILITY PRINCIPLES

As this chapter establishes, the research into the usability of voting systems described in this chapter demonstrates that scrolling DREs and PCOS systems protect voters against their own errors more consistently than other types of systems. Still, only a few studies have compared different ballots directly or definitively determined what makes one form of ballot more usable than another – *i.e.,* less prone to producing errors, more efficient, and more confidence-inspiring.[22] To be sure, usability experts have provided valuable guidelines for elections officials and the EAC that promise to improve the basic usability of voting systems. Still, until new research correlates specific design elements with measurable accuracy, efficiency, and voter confidence, such usability guidelines for voting systems will remain a work in progress. In addition, new research should reflect the performance-based thrust of the EAC's evolving voting system certification standards and study the relationships between specific features and the combined effects of the design choices embodied in a system, rather than just one facet of a design.

For this project, we have assembled the most significant lessons drawn not only from our work with voting systems, but also from other areas in which usability has improved the interaction between humans and technology. We provide the following discussion of specific areas of concern to assist elections officials in designing both the ballots for elections and the protocol for usability testing that should be conducted prior to completing such ballot design.

### DO NOT ASSUME FAMILIARITY WITH TECHNOLOGY.

Voting systems should rely as little as possible upon a voter's prior experience or familiarity with a particular type of technology or interface. Computer-based systems present the most obvious concerns for elderly or marginalized voters who may be unfamiliar with ATMs, computers, or other similar technologies. Even optical scan systems that rely upon the voter's familiarity with "SAT-style" bubbles to fill in present parallel problems. Where feasible, elections officials should address this concern in usability testing among likely voters to determine the precise effects of different design elements upon voters with limited familiarity with the technology in question. The results of such testing may also inform the design of voter education and outreach and poll worker training prior to the election. Even without usability testing, elections officials should select their jurisdiction's voting systems and design the ballots for those systems with the recognition that many voters, particularly elderly voters, are not fully familiar with technologies used in ATMs and computers. The VVSG 2005 echoes this general recommendation in one of its specific requirements: "Voting systems with electronic displays *shall not* require *page scrolling* by the voter [*e.g.,* with a scroll bar as against a clearer "next page" button]."[23]

## FOLLOW COMMON DESIGN CONVENTIONS.

Ballots and instructions should incorporate standard conventions used in product interfaces to communicate a particular type of information or message and to avoid confusion.[24] For example, the color red is typically used to indicate an emergency or error in need of attention, while green indicates a selection to move forward or activate the function in question. Consistent use of such generic conventions throughout the voting process allows the voter to rely upon her existing experience with those conventions to streamline the process and clarify otherwise ambiguous instructions, but does so without making her success depend upon any specific prior knowledge or experience. Elections officials should be aware of such conventions if they are called upon to select color schemes in designing the ballot for an election in their jurisdictions. All usability guidelines draw on commonly accepted typographic principles. For example, Drs. Kimball and Kropf suggest using text bolding to highlight certain information on the ballot:

- Ballots should use boldfaced text to help voters differentiate between office titles and response options (candidate names).[25]

The Plain Language Guidelines also include typographic principles, such as:

- Use – but don't overuse – highlighting techniques.
- Use 8 to 10 point type for text (*i.e.,* larger than that used in most government forms at the time).
- Avoid lines of type that are too long or too short.
- Use white space and margins between sections.
- Use ragged right margins.
- Avoid using all capitals.

The VVSG 2005 also includes design guidelines that address common design issues such as color, size and contrast for information:

- The use of color should agree with common conventions, *e.g.,* red should be used to indicate errors or problems requiring immediate attention.
- The minimum font size for text intended for the voter shall be 3.0 mm, and should be in a sans-serif font.[26]
- The minimum "figure-to-ground ambient contrast ratio" for text and graphics shall be 3:1.[27]

## USE PLAIN LANGUAGE IN INSTRUCTIONS AND MESSAGES.

In the late 1970s, the American Institutes for Research began a Document Design Project to promote plain language and simple design in public documents. That Project, which eventually led to the creation of the Document Design Center, conducted research into language comprehension, how real people write and read, and particular aspects of public documents that created usability problems. From this research came a set of principles called "Guidelines for Document Designers," which were intended to apply across many different disciplines.[28]

These guidelines include principles for creating instructional and informational text, such as:

- Write short sentences.
- Use the active voice.
- Use personal pronouns to address the reader.
- Avoid phrases that are long strings of nouns.
- Avoid nouns created from verbs; use action verbs.
- List conditions separately.
- Keep equivalent items parallel.
- Avoid unnecessary and difficult words.

Usability experts who focus on voting systems use these plain language guidelines in their efforts to ensure that text presented to voters at each stage of the voting process is as easy to comprehend as possible.[29] Although the benefits of most of these simple principles appear intuitively obvious, further research through usability testing of voting systems is necessary to determine the relative impacts of these rules upon the three core elements of usability (accuracy, efficiency, and voter confidence). Dr. Kimball and Dr. Kropf's findings on paper ballots represent a strong first step in this process. Based on their 2005 study, they recommend:

- Voting instructions should be short and simple, written at a low reading level so voters can read and comprehend them quickly.[30]

The VVSG 2005 echoes this suggestion:

- Voting systems "shall provide clear instructions and assistance to allow voters to successfully execute and cast their ballots independently."[31]

## LOCATE INSTRUCTIONS SO THEY WILL BE CLEAR.

Proper instructions must be presented in a manner that is helpful to voters, rather than confusing or overwhelming. According to general guidelines, instructions should be placed near the process they describe. When a procedure requires several steps, instructions should be provided at each step, rather than only at the beginning.[32] In addition, research into the impact on usability of different formats for presenting on-line information has demonstrated that, particularly for users with limited literacy, information should be presented in a single-column format rather than a multi-column format to improve readability.[33] According to research conducted by Drs. Kimball and Kropf, voters using optical scan ballots often ignored text that spanned the top of a multi-column ballot. Accordingly, they recommend that:

- Voting instructions should be located in the top left corner of the ballot, just above the first contest. That is where people in Western cultures begin reading a printed page and where respondents will look for instructions on the first task.[34]

Where possible, elections officials should design usability testing that will identify the best approach to provide clear, readable instructions to voters throughout the voting process.

## ELIMINATE EXTRANEOUS INFORMATION.

Ballot design should eliminate all extraneous information from the voter's field of vision and minimize visual or audio distractions from the task at hand.[35] Voters may become overwhelmed or confused by such unnecessary material. This phenomenon may explain in part the higher levels of "roll off" produced by voting systems that present the voter with all of the races and ballot questions at once on a single surface.[36] Even for paper ballots, Drs. Kimball and Kropf suggest that designers eliminate information not immediately necessary to vote:

- Ballots should avoid clutter around candidate names (such as a candidate's occupation or hometown).[37]

## PROVIDE CLEAR MECHANISMS FOR RECORDING AND REVIEWING VOTES.

Voting systems should clearly indicate where a voter should mark her selections, and provide ongoing feedback to the voter to ensure that she knows which selections she has already made and which remain. This information orients the voter to avoid confusion or lost votes due to such confusion. Drs. Kimball and Kropf suggest a specific guideline to help ensure that a system offers clear and unambiguous feedback to the voter as she marks her ballot:

- To minimize ambiguity about where voters should mark their votes, ballots should avoid locating response options on both sides of candidate names (this is a common problem on optical scan ballots, where two or three columns of offices and candidate names are listed on a single page).[38]

The VVSG 2005 also includes requirements that address this issue:

- "There shall be a consistent relationship between the name of a candidate and the mechanism used to vote for that candidate," *e.g.*, the button for selecting candidates should always be on the left of the candidates.[39]

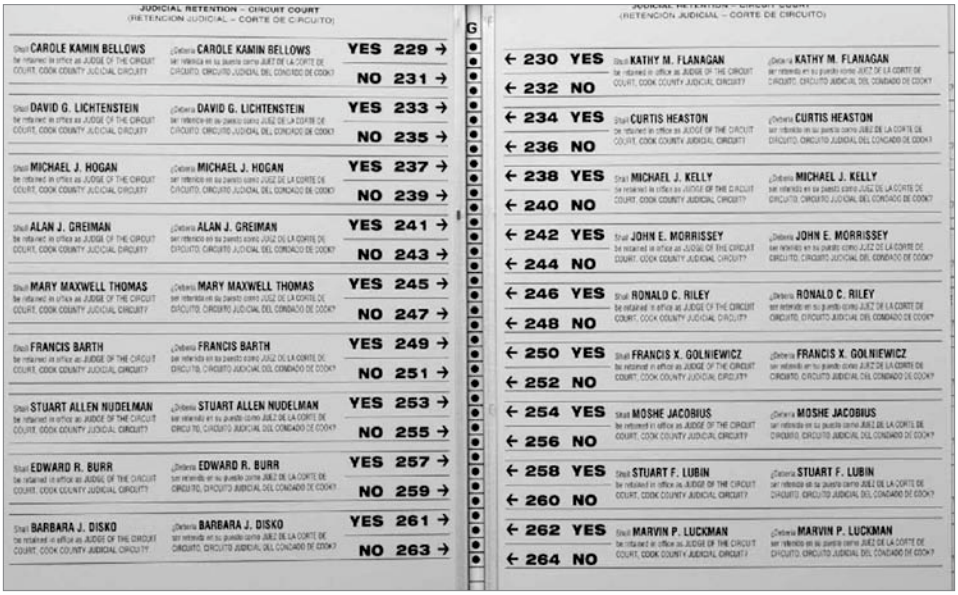
- Voting systems *shall* provide unambiguous feedback to indicate the voter's selection (*e.g.*, a checkmark beside the chosen candidate).[40]

- "Input mechanisms *shall* be designed so as to minimize accidental activation."[41]

A recent study of ballot design changes implemented in Illinois between 2000 and 2002 underscores this point.[42] In Illinois, voters must cast judicial retention votes in each election, using long lists of sitting judges for which voters must vote either "yes" or "no." In 2000, Cook County switched to a butterfly design for their punch card system, and the percentage of people who cast votes in the judicial retention elections dropped significantly.

FIGURE U1

PUNCH CARD BALLOT USED IN 2000

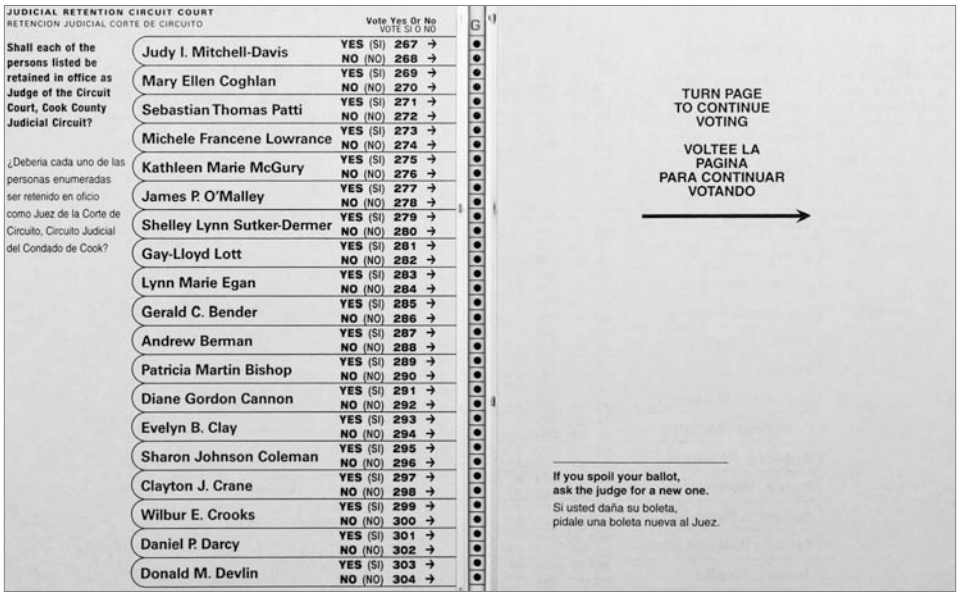



In 2002 Marcia Lausen, of Design for Democracy, and the county election department redesigned the county's ballot. Lausen and her colleagues clarified

where voters should mark their ballots by stacking all of the retention candidates in single columns on left-hand pages only.

FIGURE U2

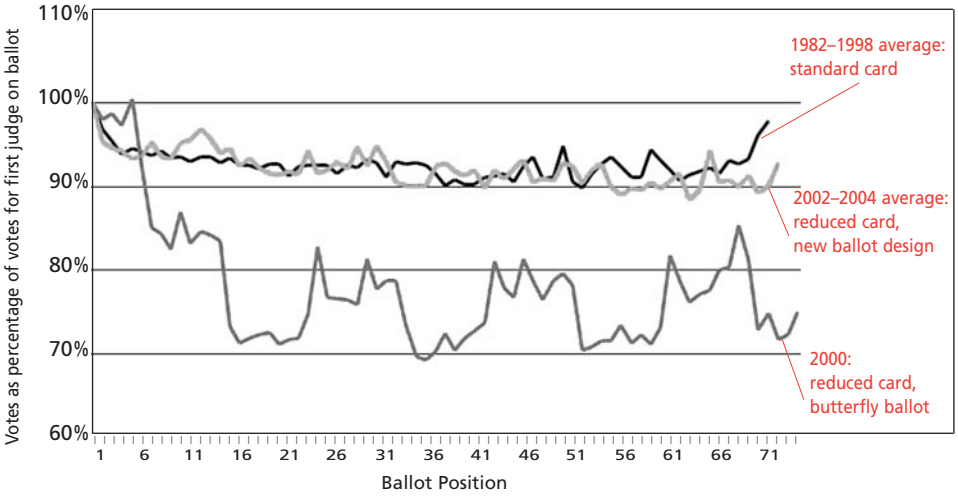
BALLOT DESIGN USED IN 2002




The improvement was dramatic. In the 2002 and 2004 elections, even while retaining the smaller-hole punch card, judicial retention voting returned to its pre-2000 levels with no abnormal loss of voters. Figure 3 shows the votes cast in sequence for Cook County retention judges before, during and after 2000. Note the peaks and valleys that correspond to page changes on the 2000 ballot. Before the change, voters would repeatedly begin again after turning the page, and then give up.

FIGURE U3

VOTES CAST FOR COOK COUNTY RETENTION JUDGES, 1982–2004



Systems that allow voters to review their choices in a clearly presented format, rather than simply asking if they are ready to cast their ballots, can reduce unintentional error.

## CREATE CLEAR CLOSURE.

Where applicable, the ballot presentation should make clear when the voter has completed each step or task in the voting process. Whether through clear organization of the ballot or through express messages on a screen, the system should seek to reduce the likelihood of voter confusion or error by instructing how to complete each task and then making clear when each task has been successfully completed. This principle should apply as well to making clear to the voter when she has completed the voting process by casting her vote. Drs. Kimball and Kropf suggest that designers use shading to separate sections of the ballot:

- Ballots should use shading to help voters identify separate voting tasks and differentiate between offices.[43]

## REDUCE MEMORY LOAD.

Voting systems should minimize the memory load on the voter, allowing her to review, rather than remember, each of her choices during the voting process. Undue memory burdens may confuse voters and lead to errors or delays. For example, systems that allow voters to review their choices in a clearly presented format, rather than simply asking if they are ready to cast their ballots, can reduce unintentional error. At least one requirement in the VVSG 2005 addresses the problem of memory load and possible confusion if the voter is required to track a contest from one part of the ballot to another:

- Voting systems "should not visually present a single contest spread over two pages or two columns."[44]

Elections officials should consider this principle in selecting a voting system, in developing usability testing to improve ballot design, and in designing the ballot and instructions for their jurisdiction.

## NOTIFY VOTERS OF ERRORS.

The voting system should plainly notify the voter of her errors and provide a clear and easy opportunity to correct such errors. In particular, a voter should be informed of any under- or overvotes prior to casting her vote. In paper-based systems such as optical scan systems, this requirement means that the scanner must be programmed to return immediately to the voter for correction any ballot that includes such an error. In DREs, the system should notify the voter of any such error and provide an opportunity and instructions to correct it. Drs. Kimball and Kropf's guidelines include:

- Ballot instructions should warn about the consequences of casting a spoiled ballot *and* explain how to correct a spoiled ballot (required by the Help America Vote Act of 2002).[45]

The VVSG 2005 also requires notification of errors, stressing the importance of noting any under- or overvotes. The guidelines also recommend that all warnings function in a similar manner, not only stating the problem, but doing so in a comprehensible manner and offering options to address it:

- Warnings to the voter should clearly state the nature of the problem and the responses available to the voter.[46]

## MAKE IT EASY TO CORRECT ERRORS.

The federal Help America Vote Act requires that voters have an opportunity to correct errors on their ballots.[47] But if correcting errors during the voting process imposes a significant burden on voters, the number of voters who choose not to make corrections increases, leading to higher residual vote rates. Accordingly, the mechanism for correcting errors must be easy both to understand and to execute. In their laboratory research on DREs, Dr. Conrad et al. found that the Diebold AccuVote-TS required the voter to de-select an erroneous candidate selection before touching her preferred candidate on the screen; this extra step caused confusion among participants and led to at least one error.[48] By contrast, other DREs under study did not require that extra step in the error correction process. The VVSG 2005 includes several requirements to provide opportunities for error correction and ensure that voters can extend a warning period if they need more time:

- DREs "shall allow the voter to change a vote within a contest before advancing to the next contest."[49]

- Voting systems "shall provide the voter the opportunity to correct the ballot for either an undervote or overvote before the ballot is cast and counted" and "shall allow the voter . . . to submit an undervoted or overvoted ballot."[50]

- If the voting system requires a response by the voter within a specified period of time, it shall issue an alert at least 20 seconds before this period expires.[51]

## RECOMMENDATIONS

Our review of usability research on various technologies, including but not limited to voting systems, points us to several recommendations in the areas of ballot design and system instructions. These recommendations should assist election officials in making purchase decisions and in maximizing a voting system's usability once it is purchased and before ballot designs and instructions are finalized:

- Do not assume familiarity with technology. Where feasible, elections officials should address this concern in usability testing among likely voters to determine the precise effects of different design elements upon voters with limited familiarity with the technology in question. The results of such testing should also inform the design of voter education and outreach and poll worker training prior to the election.

- Conduct usability testing on proposed ballots before finalizing their design. Usability testing of specific models within a type of voting system is critical if election officials are to reduce unnecessary voter errors. Election officials should not assume familiarity with technology or a particular voter interface.

- Create plain language instructions and messages in both English and other languages commonly used in the jurisdiction. Use of plain language that is easy to understand quickly is critical to avoiding voter error. Both DREs and optical scan systems produce substantially higher residual vote rates in jurisdictions with a Hispanic population of at least 30%. This suggests that plain language instructions in both English and Spanish are critical to reduce voter errors, even where Spanish language ballots are not required under the Voting Rights Act.

- Locate instructions so they are not confusing or ignored. Instructions should be placed in the top left of the frame, where possible. In addition, information should be presented in a single-column format rather than a multi-column format to improve readability.

- For both ballots and instructions, incorporate standard conventions used in product interfaces to communicate a particular type of information or message Consistent use of generic conventions (*e.g.,* red = warning or error) throughout the voting process allows the voter to rely on her existing experience to streamline the process and clarify otherwise ambiguous instructions.

- Do not create ballots where candidates for the same office appear in multiple columns or on multiple pages. Listing candidates for the same office in multiple columns or on multiple pages (as in the infamous "butterfly ballot" used in Palm Beach County, Florida in 2000, or in optical scan ballots that allow a contest to continue from one column to another) produces higher rates of residual votes (both overvotes and undervotes).

- Use fill-in-the-oval ballots, not connect-the-arrow ballots, for optical scan systems. In optical scan systems, residual votes (and especially overvotes) are less common on fill-in-the-oval ballots than on connect-the-arrow ballots. The latter design should not be used.

- Eliminate extraneous information on ballots. Ballot design should eliminate all extraneous information from the voter's field of vision and minimize visual or audio distractions from the task at hand. Voters may become overwhelmed or confused by such unnecessary material.

- Ensure that ballot instructions make clear that voters should not cast both a write-in and normal vote. Write-in lines are a source of many overvotes, as many voters select a candidate whose name is printed on the ballot and then write the same name on the write-in line. Election officials should make sure that instructions clearly state voters should not cast votes in both areas of the ballot. At the same time, state laws should be amended to require that such ballots be counted rather than set aside as spoiled, as long as both the write-in vote and the normal vote are clearly cast for the same candidate.[52]

- Provide mechanisms for recording and reviewing votes. Voting systems should provide ongoing feedback to the voter to ensure that she knows which selections she has already made and which remain. This information orients the voter to avoid confusion or lost votes due to such confusion.

- Make clear when the voter has completed each step or task in the voting process. Whether through clear organization of the ballot or through express messages on a screen, the system should reduce the likelihood of confusion or error by instructing voters how to complete each task and then making clear when each task has been successfully completed.

- Minimize the memory load on the voter, allowing her to review, rather than remember, each of her choices during the voting process. Undue memory burdens reduce accuracy, and may confuse voters and lead to errors or delays.

- Ensure the voting system plainly notifies the voter of her errors. In particular, a voter should be informed of any under- or overvotes prior to casting her vote. In paper-based systems such as optical scan systems, this requirement means that the scanner must be programmed so that the ballot is immediately returned to the voter for correction of either of these kinds of error.

- Make it easy for voters to correct their errors. If voters find it difficult to correct their own errors during the voting process, then the number of voters who choose not to make corrections increases, leading to higher residual vote rates. Accordingly, the mechanism for correcting errors must be easy both to understand and to execute without any unnecessary, extra steps to complete.

# ENDNOTES

[1] Although there is no firm consensus on precise benchmarks to measure the usability of voting systems, academics and industry researchers have developed design guidelines in other areas, most importantly in web-browser design, that can increase usability. *See* Sanjay J. Koyanl et al., U.S. Dept. of Health and Human Resources, *Research-Based Web Design and Usability Guidelines* (Sept. 2003), *available at* http://usability.gov/pdfs/guidelines_book.pdf.

[2] A full summary of the VVSG usability requirements is available at http://www.eac.gov/VVSG%20Volume_I.pdf.

[3]International Organization for Standardization, *Ergonomic Requirements for Office Work with Visual Display Terminals* at 11, ISO 9241 (1997); *see* Sharon Laskowski et al., National Institute of Standards and Technology, *Improving the Usability and Accessibility of Voting Systems and Products* at 8 (2004), *available at* http://vote.nist.gov/Final%20Human%20Factors%20Report%20%205-04.pdf.

[4] The IEEE has defined a usable voting system as one that allows voters to cast a ballot:

- Correctly – voters correctly use the voting system to register their intended selections with minimal errors.
- Efficiently – voters complete the voting process in a timely manner and without unproductive, unwanted interactions with the system.
- Confidently – voters are confident (1) in what actions they had to perform in order to vote, (2) that their votes were correctly recorded by the system, and (3) that their privacy is assured.

Institute of Electrical and Electronics Engineers, *Usability and Accessibility Standards* §§ 5.3, at 3, *at* http://grouper.ieee.org/groups/scc38/1583/documents_-_p1583/Sections%205.3%20Usability-Accessibility%20(March%2016,%202003).DOC (Mar. 16, 2003); *see* John M. O'Hara, Institute of Electrical and Electronics Engineers, *A Proposed Approach to Testing the IEEE Usability/Accessibility Standards*, *at* http://grouper.ieee.org/groups/scc38/1583/documents_-_p1583/Standards%20Testing%20White%20Paper,%20Rev%201.doc (Apr. 3, 2003).

[5] The 2005 VVSG mirrors the IEEE definition of a usable voting system, explaining that among the basic metrics for usability are:

- Low error rate for marking the ballot (the voter selection is correctly conveyed to and represented within the voting system)
- Efficient operation (time required to vote is not excessive)
- Satisfaction (voter experience is safe, comfortable, free of stress, and instills confidence).

Election Assistance Commission, *Voluntary Voting System Guidelines*, Volume I Version 1.0 at §§ 3.1 (2005), *available at* http://www.eac.gov/VVSG%20Volume_I.pdf, [hereinafter EAC VVSG].

[6] The residual vote rate does not include ballots that are not counted for reasons relating to a voter's ineligibility to vote.

[7] Stephen Knack and Martha Kropf, *Roll Off at the Top of the Ballot: Intentional Undervoting in American Presidential Elections,* 31 Politics & Policy 575-594 (2003); Michael Tomz & Robert P. Van Houweling, *How Does Voting Equipment Affect the Racial Gap in Voided Ballots?*, 47 American Journal of Political Science 46, 57 (Jan. 2003).

[8]*See, e.g.*, Robert Darcy and Anne Schneider, *Confusing Ballots, Roll-Off, and The Black Vote,* 42 Western Political Quarterly 347 (1989); Stephen M. Nichols, *State Referendum Voting, Ballot Roll-off, and the Effect of New Electoral Technology,* 30 State and Local Government Review 106-117 (1998); Stephen Knack and Martha Kropf, *Invalidated Ballots in the 1996 Presidential Election: A County-Level Analysis,* 65 Journal of Politics 881 (May 2001) *available at* http://www.vote.caltech.edu/media/documents/knack-kropf32.pdf; Michael C. Herron and Jasjeet S. Sekhon, *Overvoting and Representation: An Examination of Overvoted Presidential Ballots in Broward and Miami-Dade Counties*, 22 Electoral Studies 21 (Sept. 2001) *available at* http://elections.berkeley.edu/election2000/HerronSekhon.pdf; David C. Kimball *et al., Unrecorded Votes and Political Representation*, *in*

COUNTING VOTES: LESSONS FROM THE 2000 PRESIDENTIAL ELECTION IN FLORIDA at 135 (Robert P. Watson, ed., 2004) *available at* http://www.umsl.edu/~kimballd/unrep.pdf; R. Michael Alvarez, *et al.*, *Counting Ballots and the 2000 Election: What Went Wrong?* (Feb. 2004) *at* http://www.hss.caltech.edu/~betsy/papers/Chapter1.pdf; Justin Buchler *et al.*, *Punch Card Technology and the Racial Gap in Residual Votes*, 2 PERSPECTIVES ON POLITICS 517 (2004) *available at* http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=246600.

9 The data available to examine residual votes in American elections are still limited. Several states still do not collect data on the number of ballots cast in an election, which are needed to compute residual vote rates; instead, these states report the number of votes recorded for the contest at the top of the ballot. This practice requires researchers to seek data from local jurisdictions (counties or towns), which do not gather such data in some cases. In addition, most state and local elections officials do not gather and report data on the number of overvotes and undervotes.

Ideally, election officials would collect data on the number of voters who sign the poll book, the number of ballots cast, overvotes, and undervotes for each contest on the ballot at the precinct level (*i.e.*, the lowest level of aggregation possible). Beginning in 2004, the federal Election Assistance Commission requested that states begin to report this information for each local jurisdiction, and the EAC published the first Election Day Survey in September 2005.

Further, data on polling place conditions and procedures are extremely limited. In the last two years, researchers have started organizing teams of observers to measure polling place accessibility and other conditions. In addition to the huge cost of these studies, however, legal barriers limit their reach. In several states, like California, state law explicitly allows research teams to observe polling places during elections. In other states, like Missouri, state law prohibits researchers from conducting research in polling places. These limitations make it difficult to control for differences in polling place conditions when assessing the performance of voting systems.

10 The Institute's research has been conducted in association with researchers at the University of Rochester, the University of Maryland, Georgetown University, and the Maryland State Board of Elections.

11 *See* Fred Conrad *et al.*, *A Laboratory Evaluation of Six Electronic Voting Machines* (July 2, 2005) (A presentation given to the Usability Professionals Association) *available at* http://www.upassoc.org/usability_resources/conference/2005/Conrad.ppt.

12 As noted already, the results from Nevada may reflect that state's unique ballot options rather than the voting system used.

13 David C. Kimball and Martha Kropf, *Ballot Design and Unrecorded Votes on Paper-Based Ballots*, 69 PUBLIC OPINION QUARTERLY 508 (2005), *available at* http://www.umsl.edu/~kimballd/kkpoq05.pdf.

14 Michael J. Hanmer and Michael W. Traugott, *The Impact of Voting by Mail on Voter Behavior*, 32 AMERICAN POLITICS RESEARCH 375 (2004).

15 For earlier studies that depended principally on surveys of voters, expert review, and limited field testing, *see* Paul S. Herrnson, *et al.*, *Early Appraisals of Electronic Voting*, 23 SOCIAL SCIENCE COMPUTER REV. 274 (2005) (summarizing limited past research and presenting results of analysis of Diebold's AccuVote-TS DRE) *available at* http://theory.lcs.mit.edu/~rivest/voting/reports/EarlyAppraisalsOfElectronicVoting.pdf; Benjamin B. Bederson, *et al.*, *Electronic Voting System Usability Issues*, CHI 2003, at 145-162 (Paper from the Conference on Human Factors in Computing Systems sponsored by the Association for Computing Machinery's Special Interest Group on Computer-Human Interaction) (Apr. 5-10, 2003) (reviewing expert and non-expert subjective comments on usability of electronic voting system used in Maryland, Diebold's AccuVote-TS); Benjamin B. Bederson & Paul S. Herrnson, *Usability Review of the Diebold DRE System for Four Counties in the State of Maryland*, Univ. of Maryland (2003) *at* http://www.capc.umd.edu/rpts/MD_EVoteMach.pdf; Center for American Politics and Citizenship, *An Evaluation of Maryland's New Voting Machines* (Dec. 2, 2002) (summarizing results of exit poll survey in two Maryland counties), *available*

*at* http://www.capc.umd.edu/rpts/MD_EVoteEval.pdf.

16 *See* Gary H. Roseman, Jr. & E. Frank Stephenson, *The Effect of Voting Technology on Voter Turnout: Do Computers Scare the Elderly?*, 123 PUBLIC CHOICE 39 (2005) *available at* http://www.springerlink.com/index/K562205R35WKL415.pdf. Maryland and Florida have both shifted to DREs in recent years. An examination of the elderly population's voting patterns in these states could help test Roseman and Stephenson's findings.

17 *A Laboratory Evaluation of Six Electronic Voting Machines*, *supra* note 11, at 27.

18 Ted. Selker *et al.*, *Comparative Voting Performance of Reading Disabled Voters* (2005), *available at* http://www.vote.caltech.edu/media/documents/readingdisabledwist.doc.

19 Stephen Ansolabehere and Charles Stewart, III, "Residual Votes Attributable to Technology," *Journal of Politics* 67(2005) at 365-389; David C. Kimball and Martha Kropf, "Ballot Initiatives and Residual Ballots in the 2004 Presidential Election," paper presented at the Southern Political Science Association Annual Meeting, Atlanta, January 2006.

20 Sharon Cohen, MIT EECS MS thesis, An Active Approach to Voting Verification, http://votingtechnologyproject.org/theses/cohen-thesis_5-05.pdf.

21 The efficiency of Vote-by-Mail systems must be evaluated differently than in other systems because voters cast ballots at home and at their leisure. Thus, there are no bottlenecks at polling places to consider.

22 *See* Jonathan Goler, Ted Selker, and Lorin Wilde, *Augmenting Voting Interfaces to Improve Accessibility and Performance* (2006), *available at* http://vote.caltech.edu/reports/chi-abstract-golerselker.pdf; Ted Selker, Matt Hockenberry, Jonathan Goler, and Shawn Sullivan, *Orienting Graphical User Interfaces Reduces Errors: the Low Error Voting Machine*, *available at* http://vote.caltech.edu/media/ documents/wps/vtp_wp23.pdf.

23 EAC VVSG, *supra* note 5, at § 3.1.6(a) (emphasis added).

24 *Id.* at § 3.1.4(c)(i).

25 *Ballot Design*, *supra* note 13, at 516.

26 EAC VVSG, *supra* note 5, at § 3.1.5(d), (h).

27 *Id.* at § 3.1.5(i).

28 *See* Daniel B. Felker *et al.*, American Institutes for Research (AIR) Document Design Project, *Guidelines for Document Designers* (Nov. 1981).

29 In her work with San Francisco's Ballot Simplification Committee, for example, Dana Chisnell uses these Guidelines in preparing the instructions and digests for the Voter Information Pamphlet ("VIP") published by the Department of Elections. It is the only citizen-written VIP in the country. Most VIPs are written by attorneys who may inadvertently introduce biases into voting materials and who often are not skilled in writing plainly.

30 *Ballot Design*, *supra* note 13, at 513.

31 EAC VVSG, *supra* note 5, at § 3.1.4(b).

32 John M. Carroll and Hans Van der Meij, *Principles and Heuristics for Designing Minimalist Instructions*, *in* MINIMALISM BEYOND THE NURNBERG FUNNEL (John M. Carroll ed., MIT Press 1998).

33 *See, e.g.*, Michael Summers & Kathryn Summers, *Clear Health Communication on the Web: Making Medical Content Accessible to Low-Literacy Users* at 4 (June 2005) (unpublished paper, on file at the Brennan Center).

34 *Ballot Design*, *supra* note 13, at 516.

35 *Id.* at 528.

[36] David C. Kimball, *Assessing Voting Methods in 2002* (presented at the Midwest Political Science Association Annual Meeting) (Apr. 2003) *at* http://www.umsl.edu/~kimballd/dkmpsa2.pdf..

[37] *Ballot Design*, *supra* note 13, at 518; Richard G. Niemi and Paul S. Herrnson, *Beyond the Butterfly: The Complexity of U.S. Ballots*, 1 PERSPECTIVES ON POLITICS 317-326 (2003) *available at* http://www.upassoc.org/upa_projects/voting_and_usability/workshop2004/pol%20persp%20page%20proofs.pdf.

[38] *Ballot Design*, *supra* note 13, at 517.

[39] EAC VVSG, *supra* note 5, at § 3.1.4(c)(iii).

[40] *Id.* at § 3.1.6(b) (emphasis added).

[41] *Id.* at § 3.1.6(d) (emphasis added).

[42] Albert J. Klumpp, *Judicial Retention Elections in Cook County: Exercise of Democracy, or Exercise in Futility* (2005) (unpublished Ph.D. dissertation, University of Illinois at Chicago) (on file with the University of Illinois at Chicago Library).

[43] *Ballot Design*, *supra* note 13, at 517. Design for Democracy, a non-profit dedicated to improving ballot design, has echoed Kimball and Kropf's advice in their Election Design System. *See* Marcia Lausen, Design for Democracy, *Election Design: Models for Improvement* (Peachpit Press 2006).

[44] EAC VVSG, *supra* note 5, at § 3.1.4(c)(i).

[45] *Ballot Design*, *supra* note 13, at 516.

[46] EAC VVSG, *supra* note 5, at § 3.1.4(d).

[47] 42 U.S.C. § 15481(a)(1)(A)(ii).

[48] *A Laboratory Evaluation of Six Electronic Voting Machines*, *supra* note 11, at 44.

[49] EAC VVSG, *supra* note 5, at § 3.1.2(f).

[50] *Id.* at § 3.1.2(d), (e).

[51] *Id.* at § 3.1.6(c).

[52] Certain states already provide this protection for voters who mistakenly cast ballots with both a write-in vote and a normal vote for the same candidate. *See*, *e.g.*, Wis. Stat. Ann. § 7.50(2)(d) (2004).

## COST

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## INTRODUCTION

Of the currently available voting technologies, which is the least expensive? It's a simple question without a simple answer. A host of voting machine cost studies have produced contradictory results, particularly when it comes to assessing the two most common technologies: Direct Recording Electronic ("DRE") and Precinct Count Optical Scan ("PCOS") systems.

For instance, on March 12, 2005, TrueVoteCT issued an analysis that purported to show that PCOS "is a much less expensive voting technology than DRE machines."[1] In contrast, a New York City Election Voting Systems draft report released in February 2005 (and later updated on March 11, 2005) tentatively concluded that the initial costs of a DRE-based system would be slightly higher than the initial costs of a PCOS-based system, but that the ongoing per election costs of the DRE-based system would be far lower.[2] And, splitting the difference, the Caltech/MIT Voting Technology Project reported that "over a fifteen-year span, the combined operating and acquisition costs [of DRE and PCOS] are not significantly different."[3]

While it may be difficult to determine which voting technology is least expensive, it is quite easy to understand how seemingly straightforward analyses of voting technology costs could produce such different results: each system has different costs and benefits, and the ability to exploit these benefits is contingent upon a diverse set of jurisdiction-specific conditions. Depending upon the assumptions one makes about these conditions before crunching the numbers, each of the systems can be made to look comparatively affordable or expensive.

Of course, most election officials and concerned citizens care little about how different voting systems stack up against each other in the abstract. The real concern is how much a particular voting system will cost *them*. The purpose of this report is to assist localities and their citizens in making that determination.

## VOTING SYSTEMS BACKGROUND

The Brennan Center has analyzed the relative cost of five voting systems. In all five cases, the systems are made up of a combination of two machines: the main apparatus (*i.e.,* PCOS, DRE, or DRE with a Voter-Verified Paper Trail ("DRE w/ VVPT")), plus one accessible apparatus per polling place (*i.e.,* accessible DRE, accessible DRE w/ VVPT, or Ballot Marking Device ("BMD")).[4] Pursuant to Section 301(a)(3) of the Help America Vote Act of 2002 ("HAVA"), election jurisdictions must ensure that every polling place has one voting machine or method that allows the disabled to vote in privacy. While a DRE can be made accessible to people with disabilities with a relatively inexpensive peripheral hardware purchase, the paper ballots employed by PCOS-based systems can only be made "accessible" (within the meaning of HAVA) through the purchase of a separate BMD or accessible DRE, which greatly increases the per-polling place hardware cost.[5]

The Brennan Center sent surveys to nearly 1700 county election officials around the country, with questions regarding their current voting machine systems, purchasing plans, and compliance with HAVA.[6] Without exception, election officials who have recently purchased DREs or DREs w/ VVPT have either already purchased, or intend to purchase, accessible DREs to meet HAVA's accessibility requirements. Election officials that have recently purchased PCOS have purchased, or intend to purchase, either accessible DREs or BMDs to meet HAVA's accessibility requirements.

The following are the five voting systems currently being purchased (the "Five Voting Systems"), and they will be the subject of this report:

- The DRE System. This system is comprised of DREs (touch screen machines) with an "accessible" DRE in each polling place.
- The DRE System w/ VVPT. This system is comprised of DREs w/ VVPT, plus an accessible DRE in each polling place.
- The PCOS System. This system is comprised of PCOS machines with an accessible DRE in each polling place.
- The PCOS System with DRE w/ VVPT. This system is comprised of PCOS machines with an accessible DRE w/ VVPT in each polling place.
- The PCOS System with BMD. This system is comprised of PCOS machines with a BMD in each polling place.

## SUMMARY OF CONCLUSIONS

Our conclusions about cost can be broken into two categories. "General Conclusions" are the few universal rules that govern the cost of voting systems independent of jurisdictional considerations. "Jurisdiction-Dependent Conclusions" reflect the effect of localized factors on total system cost. A full explanation of these conclusions can be found in "Analysis of Total Cost" below.

### GENERAL CONCLUSIONS

Our study of the cost of voting systems has shown the following conclusions to be true across jurisdictions:

- The initial costs of a voting system are likely to be a small percentage of the cost over its total life-span. Voting systems that initially cost a jurisdiction less money may end up being more expensive than other systems after a few years.
- DRE Systems without VVPT are less expensive than similar DRE Systems

w/ VVPT *under all circumstances, for both initial and ongoing costs.*

- PCOS Systems (with accessible DREs) are less expensive than similar PCOS Systems with BMDs *under all circumstances, for both initial and ongoing costs.*

- Vendors offer significant volume discounts. To the extent that counties and states can pool their purchases, they are likely to save considerably in the purchase of their voting systems.

## JURISDICTION-DEPENDENT CONCLUSIONS

The relative cost of DRE-based and PCOS-based systems, in particular, will vary greatly from one jurisdiction to the next. The Brennan Center has identified seven jurisdiction-dependent factors that appear to be most significant in determining the initial and/or long term cost of voting systems. Localities should consider each of these factors when attempting to get a complete picture of the long term cost of a voting system. They can use the Cost Calculator to assist them in weighing these factors:

1. How many registered voters are there per precinct/polling place?

2. What percentage of votes is cast early?

3. How much will the jurisdiction need to pay for ballots?

4. How many elections are held per year?

5. How much programming assistance will the jurisdiction need?

6. How much poll worker and other training will the jurisdiction need?

7. Will the county be forced to incur transportation and storage costs for the voting machines?

Each of these factors, by itself, can dramatically alter the long term cost of a voting system. Below is a chart detailing how the total cost of DRE- and PCOS-based systems are likely to be affected by each factor.

TABLE C1

JURISDICTION-DEPENDENT COST FACTORS

| Factor | PCOS-based Systems | DRE-based Systems |
|---|---|---|
| 1. More voters per precinct/polling place | No Effect | More Expensive |
| 2. More votes cast early | No Effect | More Affordable[7] |
| 3. Higher cost for ballots | More Expensive | Marginally More Expensive (absentee ballots) |
| 4. More elections per year | More Expensive | Marginal Effect |
| 5. Using vendor for programming | No Uniform Answer | No Uniform Answer |
| 6. Additional poll worker and other training | More Expensive | More Expensive |
| 7. Additional transportation and storage | More Expensive | More Expensive |

Factors 1 and 2 relate to how many voters a jurisdiction can place on each machine. As discussed in greater detail *infra* pp. 140–141, one of the primary benefits of PCOS-based systems is that PCOS machines can handle many more voters in a single day than DRE-based systems. This means that jurisdictions with high numbers of voters in a single precinct or polling place would not incur as great an increase in hardware costs for a PCOS-based system as for a DRE-based system. On the other hand, this advantage to PCOS-based systems could be reduced if a large percentage of votes are cast over several days prior to Election Day; one DRE can handle many more votes over several days than in a single day, since the most salient constraint on the number of voters a DRE can process is the amount of time it takes each user to vote.

Factors 3 and 4 relate to the cost of paper ballots, one of the most expensive ongoing costs for all Five Voting Systems. PCOS-based systems use many more paper ballots than DRE-based systems, which will primarily use paper ballots for absentee voting. DRE machines themselves do not use paper ballots. The more a jurisdiction has to pay for ballots, and the more ballots it has to print, the more expensive PCOS-based systems will become.

Factors 5 through 7 will be particularly difficult for jurisdictions to quantify and will require extensive investigation. As discussed in greater detail *infra* pp. 146–151, such investigation will have to include the technical sophistication of county employees and poll workers, whether and to what extent counties can utilize available resources for a new voting system, and what type of voting system the jurisdiction previously used. We have included two case studies that detail the experience of purchasing a new voting system to assist jurisdictions in determining what questions to ask when conducting this investigation.

## METHODOLOGY

The Brennan Center was faced with two major challenges in developing a method for comparing the costs of voting systems. They were: (1) finding out what jurisdictions were actually paying for voting systems, in both the short and long term; and (2) identifying the key jurisdiction-dependent factors that made costs of the same system vary so much from one jurisdiction to another.

### DATA COLLECTION

The Brennan Center took the following steps in order to collect a comprehensive dataset representing the actual costs incurred by jurisdictions in purchasing and implementing new voting systems:

- Contacted the 324 jurisdictions believed to have purchased one of the Five Voting Systems since Election Day 2002[8] and requested copies of their most recent voting machine contracts or final vendor bids ("Contracts and Bids").[9]

- Sent surveys (the "Follow-Up Surveys") to, and conducted follow-up interviews with, the 35 jurisdictions that provided data in response to our request, in order to identify costs not enumerated in the Contracts and Bids.[10]

- Sent cost surveys to 1,694 counties nationwide (the "Cost Surveys") to supplement the data acquired in steps 1 and 2, particularly for the purposes of estimating the costs of ballots and identifying other factors that affected the short- and long-term costs of purchasing a particular voting system.[11]

- Contacted six major vendors regarding costs and policies associated with their voting systems.[12]

### DATA ANALYSIS

Using the Contracts and Bids, interviews with vendors and election officials, as well as the Cost Survey and Follow-up Survey responses, the Brennan Center calculated the initial and ongoing costs of voting machines for various jurisdictions. From this information, we identified the way in which certain jurisdiction-dependent factors appeared to affect those costs.

For the purpose of performing this analysis, we were forced to make a number of assumptions. Where possible, these assumptions are based upon information gleaned from the Cost Surveys. We summarize them below:

- Life Span and Repair. In estimating the cost of systems, we have assumed that the life span of each system will be exactly the same. We assumed that

jurisdictions will enter into the up-front maintenance agreements, offered by most vendors, which cover most repair costs.

- Conglomeration of Machine Type. We have not distinguished between vendors when calculating the cost of the various system types, and our cost estimates are based on the median price charged for hardware, software and consumable goods for each type of system. Our discussion of the cost of DRE-based systems is limited to systems that use "scrolling" as opposed to "full-face" DREs.

- Inflation, Time Value of Money. In projecting costs over time, we have assumed there will be no increase in licensing, maintenance fees, or the purchase price for consumables or replacement parts. Furthermore, we have computed total costs without considering the "time value" of money, *i.e.,* the balancing of short- and long-term costs in making an initial purchasing decision.

- Number of Ballots Purchased. We have assumed that jurisdictions using PCOS machines will purchase one ballot per registered voter for every election.

- Growth/Changes in Jurisdiction. In estimating and projecting the overall cost of voting systems, we have not factored in the costs that may be incurred as a result of population or political changes in the jurisdiction.

- Other Costs. Our "Analysis of Total Cost" does not take account of all possible costs associated with voting systems, but rather includes only those factors found to have the greatest influence on the cost of purchasing, operating, maintaining, and using the voting systems.

For a more detailed discussion of these assumptions, *see* Appendix C.

# ANALYSIS OF TOTAL COST

We have detailed the most common initial and ongoing costs for hardware, software, and consumables in Appendix D.[13] Our analysis of total cost, below, is meant to assist jurisdictions in understanding how these individual costs, over time, will affect the overall cost of a voting system.

## GENERAL CONCLUSIONS

The following conclusions can be made independent of jurisdictional considerations.

### OPERATING COSTS ARE LIKELY TO EXCEED INITIAL COSTS OF VOTING SYSTEMS.

The Brennan Center has analyzed both initial and ongoing costs of the Five Voting Systems. Many jurisdictions are most concerned with initial costs at the time of purchase. In part, this concern is fueled by the need to ensure that federal funds allocated to the states pursuant to HAVA will pay for new machines in their entirety.

However, initial costs of information technology systems like voting machines are generally only a small portion of their total, life-span cost. The life-span costs include the purchase and use of consumables like ballots, paper, and ink, as well as "costs associated with operations, maintenance, upgrades and training."[14] In fact, "within a few years of initial purchase, many voting system jurisdictions have found that other nonprocurement expenditures exceed the initial purchase cost [of voting systems]."[15]

As demonstrated in the next section, "Jurisdiction-Dependent Factors," voting systems that initially seem least expensive will often become more expensive than other systems after a few years. Some jurisdictions may decide that, given the constraints of current funding for voting systems and the time value of money, they care most about a voting system's initial costs. At the very least, they should be aware that, depending upon facts specific to their locations, the costs of the Five Voting Systems are likely to change substantially over time.

### DRES ARE LESS EXPENSIVE THAN DRES w/ VVPT.

Among jurisdictions that have decided to purchase a DRE-based system, rather than a PCOS-based system, there is often significant debate over whether the DRE-based system should have VVPT. Not surprisingly, DREs without VVPT are less expensive than similar DREs w/ VVPT under all circumstances. This is true not only because of the additional hardware and printing costs associated with DREs w/ VVPT,[16] but also because voting on DREs w/ VVPT takes more time than voting on DREs without VVPT.

Voters using VVPT systems must wait for the paper record to print, and then they are asked to review it. Based upon follow-up interviews, we estimate that voting takes 10% longer on DREs w/ VVPT than on DREs without VVPT.[17] As a result, we have assumed that jurisdictions purchasing large numbers of DREs w/ VVPT will have to purchase a slightly higher number of DREs than they would if they purchased a system without VVPT.

### ACCESSIBLE DRES ARE LESS EXPENSIVE THAN BMDS.

Purchasers of PCOS-based systems must buy one accessible machine for each polling place; in general, that accessible machine will either be an accessible DRE or a BMD. Our statistical sample of BMDs is small, since few jurisdictions have yet to buy these machines (in fact, the only contracts or bids for BMDs that we have found are for ES&S's Automark).

Nevertheless, it seems safe to conclude that currently, BMDs are significantly more expensive than accessible DREs. BMDs are still a relatively new technology, and there is reason to believe that their cost will decrease over time. Some jurisdictions have chosen BMDs over accessible DREs because they prefer to have a single ballot-based system (which, theoretically, could lead to lower costs for audits and storage; *see* discussion of storage costs, *infra* pp. 149–151.

### MOST VENDORS OFFER VOLUME DISCOUNTS.

Regardless of what voting system a jurisdiction purchases, large purchases are likely to produce significant savings over smaller purchases. Many contracts and bids that we have reviewed provide purchasers with volume discounts. This means that a jurisdiction can get better prices if it purchases more machines. Accordingly, we recommend that states negotiate with vendors directly, rather than allowing counties to do so individually. Moreover, to the extent it is possible, counties and states will probably receive significant reductions if they make purchases together to take advantage of volume discounts.

Below are some examples of volume discounts provided by vendors that we discovered after reviewing the Contracts and Bids.

#### Accupoll

Of all vendors, Accupoll's volume discounts were the most consistent across bids. In both Iowa and Texas, Accupoll's flagship DRE machine, the AVS-1000, began at $3,688 and was discounted by 10% when more than 500 units were purchased. When a jurisdiction purchased 5,000 machines, the price of the AVS-1000 decreased by 15%.[18]

### Diebold

Diebold offered Iowa jurisdictions the AccuVote-OS PCOS scanner at $5,250 for counties that purchased 100 PCOS machines or fewer. The price was reduced to $4,995 for purchases of 101–200 machines, and $4,800 for purchases of more than 200 machines.[19]

In the final Diebold bid to Texas (the "Texas Bid"),[20] Diebold offered Texas counties the AccuVote-OS scanner for $6,400. One percent was subtracted for purchases of more than 50, 3% for more than 100, 5% for more than 500, and 7% for more than 1,000.[21]

A number of Arizona counties purchased the AccuVote-OS together and received what appears to be a significantly reduced price for the AccuVote-OS: they paid a flat price of $4,800 for each machine (including necessary accessories, such as ballot boxes).[22]

Diebold offered its primary DRE, the AccuVote-TS, to Iowa counties (the "Iowa Bid") for $3,150 for the first 125 machines purchased. This was discounted by an additional $50 per machine at each of the following quantities: 325, 550, 1,000, 2,000, and 3,000.[23] In its Texas Bid, Diebold offered the AccuVote-TS to Texas counties for $3,195. It provided a $50 discount per machine for the same quantities as in the Iowa Bid.[24]

San Diego County, CA, received an "allowance" or discount of $11 million for its purchase of voting equipment, including 8,500 AccuVote-TSX machines at $3,195 per machine.[25]

### ES&S

ES&S did not explicitly offer a volume discount for its main PCOS product, the Model 100 ("M100"), in any of the Contracts or Bids we reviewed. However, counties that purchased more machines appeared to receive better prices. For instance, LaSalle County, Illinois, which purchased 100 M100s, paid $3,752 per M100 scanner, while Menard County, Illinois, which purchased only 11 paid $4,400 per M100 scanner.[26]

The only explicit mention of a volume discount for the ES&S iVotronic DRE machine in the ES&S contracts and bids we have reviewed was in ES&S's Texas bid. For Texas counties, the 15" iVotronic began at $2,496 and was discounted by an additional $50 at each of the following quantities: 25, 100, 250, 500, 1,000, 2,000, and 10,000.[27] Among the other contracts and bids we reviewed, the cost of the 15" iVotronic was relatively constant at about $3,000 ($3,200–3,500 for the accessible version).

## JURISDICTION-DEPENDENT FACTORS

As already discussed, the Brennan Center has identified seven jurisdiction-dependent factors that are likely to affect the total cost of purchasing a particular voting system. They are:

1. How many registered voters are there per precinct/polling place?
2. What percentage of votes is cast early?
3. How much will the jurisdiction need to pay for ballots?
4. How many elections are held per year?
5. How much programming assistance will the jurisdiction need?
6. How much poll worker and other training will the jurisdiction need?
7. Will the county be forced to incur transportation and storage costs for the voting machines?

We can see how important some of these factors are by examining the likely cost of purchasing each of the Five Voting Systems[28] in three seemingly similar counties that responded to our Cost Survey: McLeod County, Minnesota; Curry County, New Mexico; and Lyon County, Kansas.[29] All three jurisdictions are rural counties, with approximately 20,000 registered voters. Our estimates of their likely costs are based upon the median prices for hardware, software, and services that have been charged for each system (a) in the Contracts and Bids and (b) as reported to us in the Cost Survey Responses and Follow-up Interviews. *These estimates are not based upon actual bids received or contracts entered into by any of the three counties.*[30]

Nor do these estimates take into account jurisdiction-dependent factors 5 through 7. These are factors that are unique to each county, but were not possible for us to estimate without the counties performing extensive investigations.[31]

*We do not intend the analysis below to serve as recommendations to any of these counties regarding which system they should purchase.* Nevertheless, the graphs below starkly demonstrate how different the costs of the same system can be, even to counties that appear to have similar needs.

We can see that in Curry County, the initial cost of purchasing any of the Five Voting Systems seems roughly equal, but that after 20 years, PCOS-based systems are likely to cost the county much more than DRE-based systems.

By contrast, in Lyon County, PCOS-based systems start out significantly less expensive than DRE-based systems. After 20 years, the cost of three systems – the

FIGURE C1

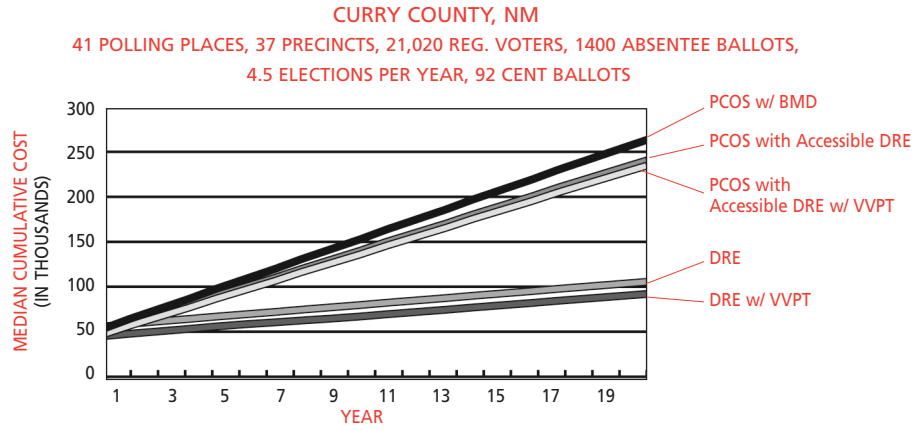



FIGURE C2

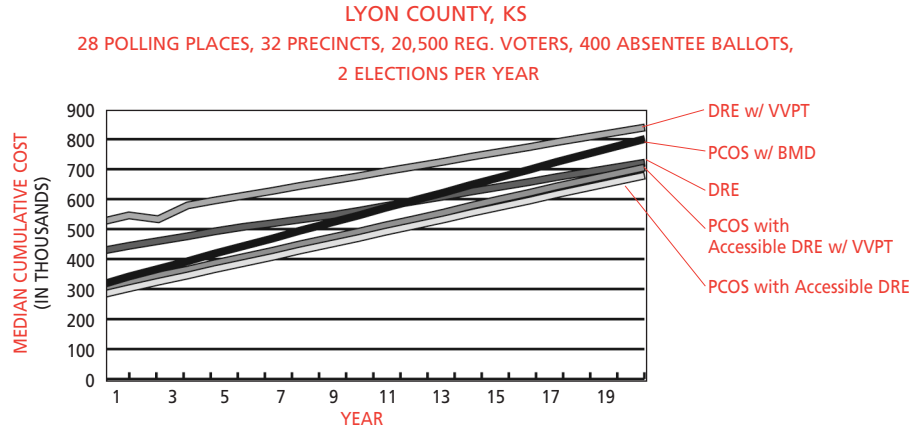
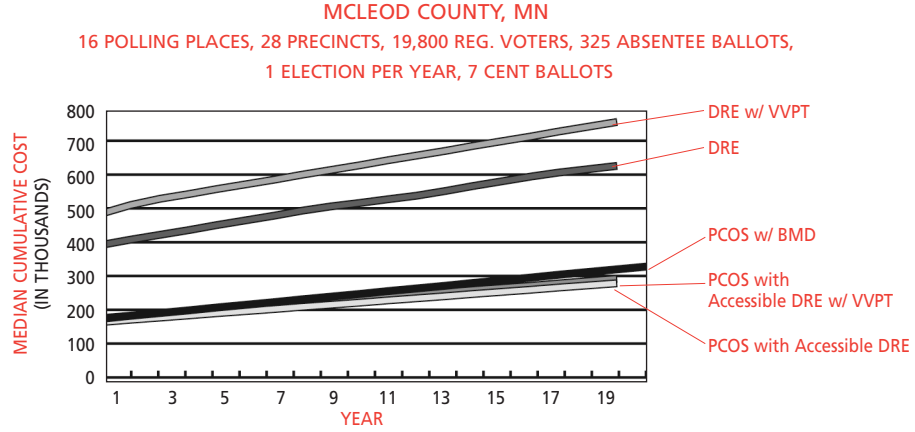



FIGURE C3




PCOS System, the PCOS System with accessible DRE w/ VVPT, and the DRE System – appear roughly equal in total cost. The DRE System w/ VVPT is significantly more expensive than these three systems, and the PCOS System with BMD is most expensive of all.

Finally, in McLeod County the three PCOS-based systems start out the least expensive. We project that after twenty years, they remain the least expensive. Some patterns remain constant for all three counties. For instance, DRE Systems without VVPT are less expensive than DRE Systems w/ VVPT, both initially and over time, in every county. And PCOS Systems (with accessible DREs) are less expensive than PCOS Systems with BMDs initially and over time in every county.

But how do we explain the differences? Why are PCOS-based systems initially so much less expensive in McLeod County, but roughly the same price as DRE-based systems in Curry County? Why do initial and long-term costs seem to correlate by system in McLeod County, while in Lyon County, some systems (in particular the PCOS System with BMD) have a low initial price, but are projected to cost the county much more over twenty years? We can find the answers to these questions in the information each county gave us.

PCOS-based systems are initially so much less expensive in McLeod County because McLeod County has more than 1,000 registered voters per polling place (specifically, 16 polling places, 28 precincts, and 19,800 registered voters).[32] If it so chooses, McLeod County can limit its purchase to just 16 PCOS machines, or one per polling place. PCOS machines have been shown to handle as many as 3,500 voters in a single Election Day.[33] At approximately $5,000 per PCOS scanner, the primary piece of hardware for the PCOS-based systems will cost McLeod County about $80,000.[34] To comply with HAVA's accessibility requirements, McLeod County will also have to purchase 16 BMDs or accessible DREs. This would cost the County an additional $48,000 to $90,000.

By contrast, our review of the Contracts and Bids show that, on average, counties will purchase one DRE for every 180 registered voters. This means McLeod County would have to buy at least 110 DREs if it purchased one of the DRE-based systems. As the median cost of the DRE unit is around $3,000, McLeod County would likely be forced to pay approximately $325,000, or about twice as much on the DRE units as on PCOS scanners and BMDs or accessible DREs.[35]

In Curry County, there are 21,020 registered voters, *but 41 separate polling places;* this means PCOS-based systems offer less of a savings than in McLeod County.[36] Like McLeod County, Curry County would probably have to buy at least 110 DREs, including 41 accessible units (one for each polling place). The number of PCOS scanners it would have to buy would greatly increase: with 41 separate polling places, it will need to buy at least 41 PCOS machines and 41 accessible units (either BMDs or accessible DREs). This is more than triple the number of PCOS machines and accessible units than McLeod County would have to buy. And it means that Curry County will probably need approximately $400,000 for the PCOS scanners and accessible units, an amount substantially similar to what it would pay for DRE hardware.[37]

We project the cost to McLeod County of owning a PCOS-based system will not increase greatly over time. By contrast, it rises steadily in Lyon County, and even

more significantly in Curry County. One reason is the amount we estimate each county would pay for ballots, which are used only on optical scan machines. McLeod County pays just seven cents for each PCOS ballot.[38] In contrast, Curry County pays 92 cents.[39] Lyon County does not have a PCOS-based system; we estimated that Lyon County would pay 30 cents a ballot, which is the average price paid by counties that responded to our Cost Survey and use a PCOS-based system.

The difference in the cost of ballots between McLeod and Curry County is 85 cents per ballot. Both counties are likely to print close to 20,000 ballots for most elections.[40] This means the difference in the cost of printing ballots for each election could run as much as $17,000. Over 20 years, this difference becomes quite substantial.

Another, but related, difference between the counties is the *number* of elections held per year. McLeod County holds approximately one election per year, Lyon County holds two, and Curry County averages 4.5.[41] The more elections a county holds, the more ballots it will have to consume, and the more expensive a PCOS-based system is likely to become over several years.

These are some of the explanations for the projected differences in costs. In fact, as already discussed, there are at least seven factors that could dramatically affect the initial and long term costs of voting systems. We discuss each of them below.

## REPRESENTATIVE MODEL FOR DEMONSTRATING THE IMPACT OF THE SEVEN COST FACTORS: AMALGAM COUNTY, USA

To demonstrate the impact of each of these factors, we have created a composite jurisdiction. "Amalgam County" is a jurisdictional composite that is meant to represent a typical county in the United States. Using information provided in the EAC 2004 Election Day Survey, we determined that, as of 2004, the "average" county in the United States had approximately 39 polling places, 56 precincts, and 53,946 registered voters.[42] Based upon the results of our Follow-Up and Cost Surveys, we assumed that Amalgam County would pay 30 cents per PCOS ballot (the average price paid by survey respondents) and conduct two elections per year (the average number conducted by survey respondents). Finally we assumed that Amalgam County would pay the vendor to program the machines and ballots (in most Contracts, counties opted to have the vendor program the machines, at least initially).

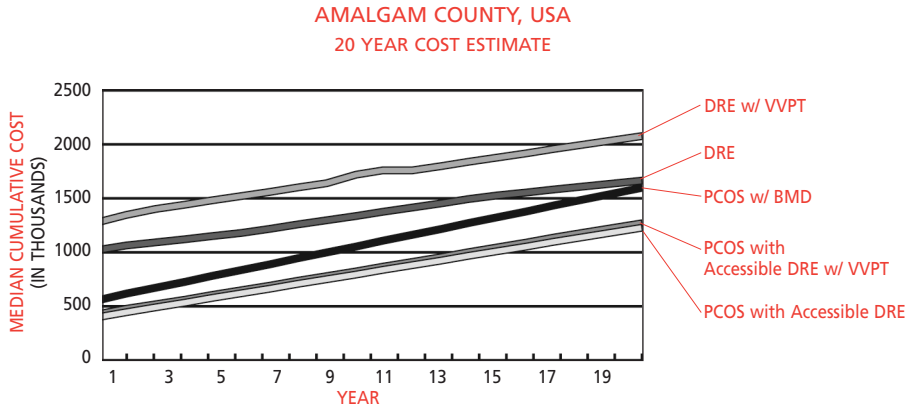
We made no assumptions about the previous voting system owned by Amalgam County, or the amount it would pay for training, transportation, or storage for machines. These factors are so idiosyncratic by county that we did not believe it made sense to make assumptions about these costs.[43] However, using data we collected from jurisdictions in our Cost Surveys, we do show how each of these costs can dramatically affect the total cost of any of the Five Voting Systems *infra* pp. 148–151.

TABLE C2
PROFILE OF AMALGAM COUNTY 2006

| | |
|---|---|
| Registered Voters | 53,946 |
| Polling Places | 39 |
| Precincts | 56 |
| Price Per Ballot | $0.30 |
| Elections Per Year | 2 |

Using the data provided in Table C2, we are able to chart out a 20-year projected cost analysis of the Five Voting Systems for Amalgam County:

FIGURE C4




For Amalgam County, the PCOS System with accessible DRE is the least expensive voting system, followed by the PCOS System with accessible DRE w/ VVPT, and then the PCOS System with BMD. The initial costs for all three of these systems should be somewhere around $500,000. After 20 years, the total cost of the PCOS System with accessible DRE and PCOS System with accessible DRE w/ VVPT will increase at roughly the same rate, to well over $1 million. The cost of the PCOS System with BMD increases more sharply over time. This is largely because ES&S charges higher hardware maintenance fees for BMD machines than for any other machine.[44]

More expensive initially, and over time, are the DRE-based systems. These two systems will start out costing somewhere between $1 million and $1.5 million. After 20 years, the operating costs of the DRE System should run over $500,000, for a total cost of more than $1.5 million. The total cost of the DRE System w/ VVPT will likely come to more than $2 million.

Among the DRE-based systems, the DRE System (without VVPT) is less expensive than the DRE System w/ VVPT. This is true both initially and over time. As already discussed, this result should not be surprising: DREs w/ VVPT have additional hardware and printing costs. Moreover, DREs w/ VVPT are slower than DREs, which we have assumed would force Amalgam County to purchase more of them.

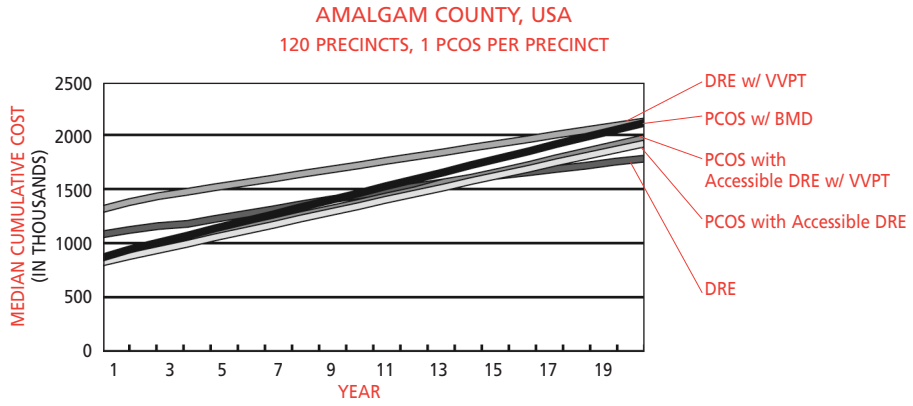
### NUMBER OF POLLING PLACES/PRECINCTS

A primary reason that PCOS-based systems are less expensive in Amalgam County is that the number of registered voters per precinct and polling place is relatively high: 963 voters per precinct and 1,383 voters per polling place. This means that Amalgam County needs to purchase only one PCOS machine for

every 1,000 or so registered voters. By contrast, it must purchase one DRE for every 180 registered voters and one DRE w/ VVPT for every 162 voters.

But what happens if the county has more precincts and fewer registered voters per precinct? For instance, if the county had 120 precincts, there would be approximately 450 voters per precinct (as opposed to the 963 voters in our original analysis). Almost 30% of the counties that responded to our Cost Survey had precincts with 450 or fewer registered voters per polling place. Assuming that Amalgam County had 120 precincts rather than 56, and that it purchased one PCOS machine for each of these 120 precincts, the initial and long-term cost of all three PCOS systems would greatly increase compared to our earlier analysis.

FIGURE C5




We can see in Figure C5 that under these circumstances, the initial costs of all three PCOS-based systems are much closer to the initial costs of the three DRE-based systems. Moreover, by about year 14, Amalgam County is projected to have spent more on the PCOS System with accessible DRE than it would spend on the DRE System. Similarly, at about year 20, the cost of the PCOS System with BMD is projected to surpass the DRE System w/ VVPT. This is because, in addition to the extra cost created by the necessity of purchasing additional PCOS machines, over time Amalgam County will have to pay more for maintaining and operating these extra machines.

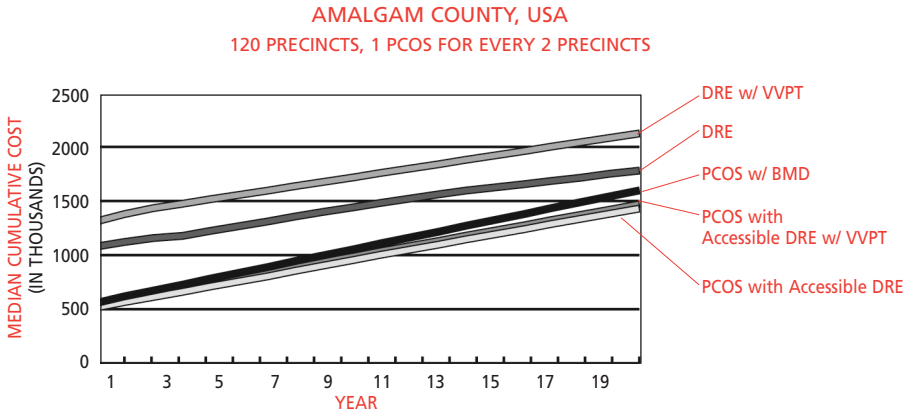
Does this mean that, all other factors being equal, counties with less than 450 voters per precinct should assume that PCOS-based systems will eventually become more expensive than DRE-based systems? Not necessarily.

Some counties, such as Amalgam County, will have multiple precincts per polling place.

By putting two precincts on a single machine, these jurisdictions can significantly cut the initial and long term costs of purchasing a PCOS-based system.

In Figure C6 we see that initial costs for the PCOS-based systems start much lower than if Amalgam County purchased one machine for every precinct. Moreover, in the long term, the PCOS-based systems appear to remain less expensive than the DRE-based systems. Again, with few machines, a county is likely to pay less in maintenance and programming for those machines.

FIGURE C6




We make an important caveat to this projection, however: voting results must be totaled, audited, shipped and stored by precinct. The separation of ballots by multiple precincts could be a hardship at the close of Election Day. Moreover, the ballots themselves would become more expensive: to the extent that a polling place is using only one PCOS machine to count multiple precincts, each precinct's ballots must be coded with an extra bar, so that they can be distinguished by the machines.[45] These facts make using PCOS machines on multiple precincts more expensive than they appear in the chart above.

Some vendors claim that their PCOS scanners can handle as many as five to seven ballot types.[46] This would theoretically allow urban districts like New York City or Chicago – which have several precincts per polling place – to place as many as seven precincts on a single scanner. In practice, however, few, if any, jurisdictions do this. For instance, in recently deciding to purchase a PCOS-based system, Cook County, Illinois assumed it would place a maximum of two precincts on a single PCOS machine. It judged placing more precincts than two on a single PCOS machine as too complicated.[47]

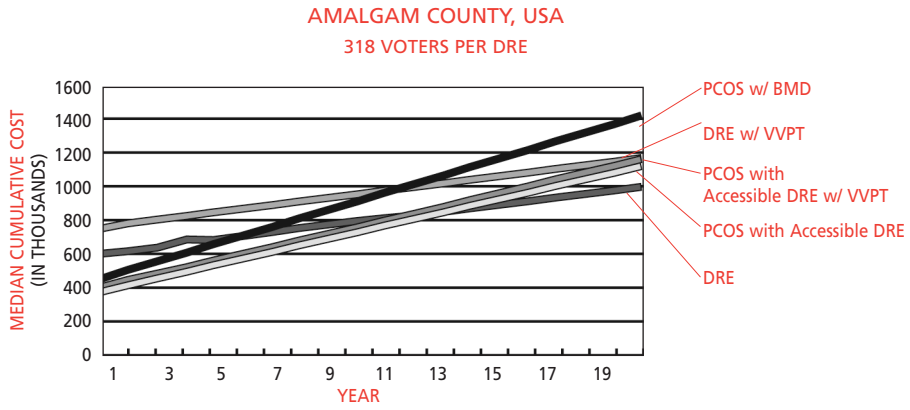
### PERCENTAGE OF EARLY VOTING

The analysis above assumes that counties will purchase one DRE for every 180 voters. But what if a large number of voters vote early? Will it be necessary to buy so many DREs? Maybe not. In such cases, counties may calculate that they can afford to buy fewer DREs per precinct.[48]

Going back to our original assumptions about Amalgam County, let's assume that

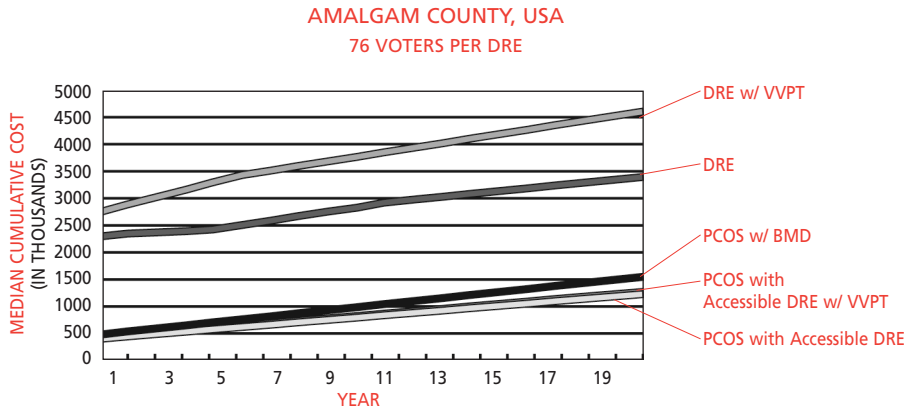
there are 53,946 registered voters. In the 2004 Presidential Election in Arizona, 40.8% of all voters voted early.[49] If Amalgam County knew that so many of its voters were going to vote early, it might not need to buy one DRE for every 180 voters. Instead, it might purchase one DRE per 318 registered voters, as Chambers County, Texas appears recently to have done.[50] This would drastically reduce the relative cost of DRE-based systems.

FIGURE C7




On the other hand, some counties have determined that one DRE per 180 registered voters is too few. Posey County, Indiana, for instance, bought one DRE for every 76 voters. These jurisdictions may fear that voters will need extra time because they are unfamiliar with the DRE machines, or they may believe that their counties are growing quickly enough that it is better to buy additional DREs as soon as possible. In any case, we can see in Figure C8 that if Amalgam County followed the conservative path of Posey County, Indiana, DREs would appear to be much more expensive than PCOS machines over both the short and long term.

FIGURE C8



## COST OF BALLOTS

Responses to our Cost Surveys and Follow-Up Interviews showed that ballots often represent the single highest consumable cost for jurisdictions; this is true across systems. In all systems, some ballots are used; even in jurisdictions that use only paperless DREs, absentee votes are recorded by ballot.

PCOS-based systems are affected most by the cost of ballots because all votes, whether cast absentee, early, or on Election Day, are cast on paper ballots. Where paper ballot costs are high, the PCOS-based systems become much more expensive over time. Our Cost Survey responses showed that jurisdictions can pay anywhere between 7 and 92 cents per paper ballot. The explanation for these varying costs are many: some jurisdictions have more complex ballots; some want to spend more on design to ensure that the ballots are not confusing; some must rely on vendors who charge high prices to supply their ballots; while some print their own ballots.[51]

The median price of ballots for jurisdictions that responded to our survey was 30 cents, so this is the amount we have assumed Amalgam County would pay. But we can see in Figures C9 and C10 how differently the cost of PCOS-based systems, in particular, look if we assume a very high or low price per ballot:

FIGURE C9

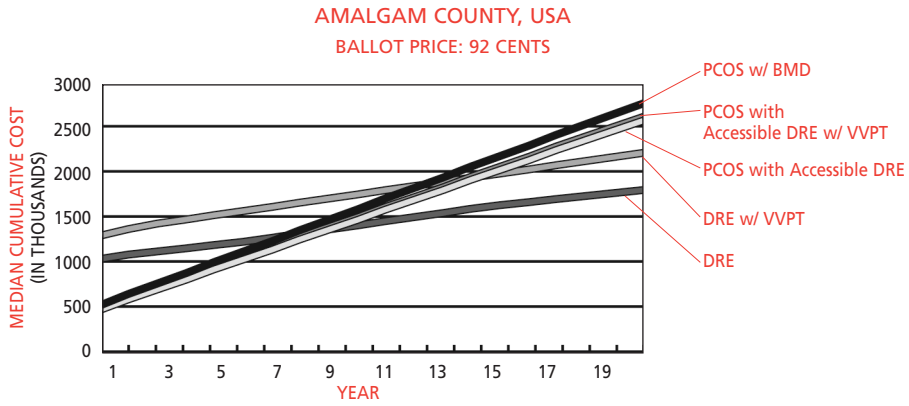
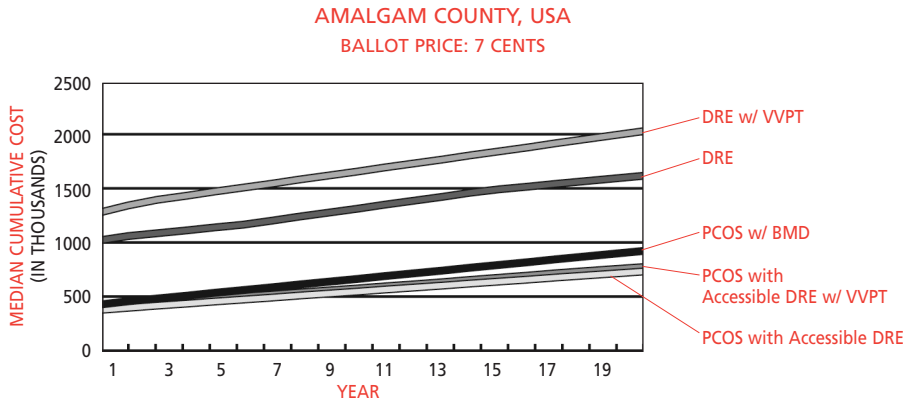



FIGURE C10



Where a county pays just seven cents per ballot, as McLeod County, Minnesota does, the cost of owning a PCOS-based system remains relatively low over time. The gap between the cost of PCOS-based systems and the cost of DRE-based systems actually grows over time. This is mostly due to the extra maintenance costs that will likely be incurred for DRE-based systems because many more machines would be required than if the county purchased a PCOS-based system.

By contrast, where a county must pay 92 cents per ballot, as in Curry County, New Mexico, long-term costs of PCOS-based systems balloon. If Amalgam County was forced to pay 92 cents per ballot, the three PCOS-based systems would become more expensive than the DRE System (without VVPT) by year 8, and more than the DRE System w/ VVPT by year 12.

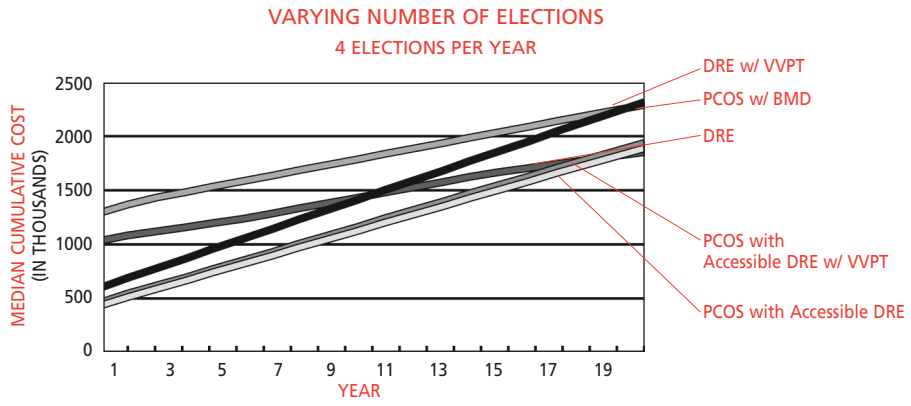
For this reason, when considering which voting system to purchase, counties should investigate carefully how much ballots are likely going to cost them.

### NUMBER OF ELECTIONS PER YEAR

Just as a high cost of ballots makes the long term cost of PCOS-based systems greater, so too does a high number of elections per year. In both cases, the consumption of ballots increases the operating costs of PCOS-based systems.

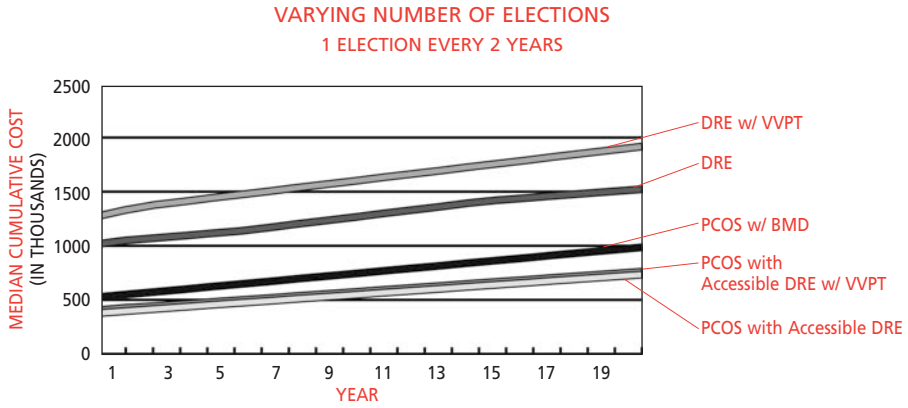
The average number of elections per year varies from state to state and county to county. Some jurisdictions reported to us that they have as few as one election every two years.[52] Others had as many as 4 or 4.5 per year.[53]

FIGURE C11




Again, going back to our original assumptions about Amalgam County, we can see in Figure C11 that if Amalgam County had 4 elections per year, PCOS-based systems become much more expensive over time.[54] After 20 years, the amount spent on PCOS-based systems will equal the amount that would be spent on DRE-based systems.

FIGURE C12




By contrast, if Amalgam County held only one election every two years, as in Sherburne County, Minnesota,[55] the long term costs of PCOS-based systems remain relatively low. In fact, we project that the total operating costs for the DRE-based systems will be greater over the 20-year period than it will be for the PCOS-based systems.

### PROGRAMMING

Responses to our Follow-Up Interviews and Cost Surveys show that programming costs are often among the highest annual costs for operating voting machines. *We did not find significant differences across systems for programming costs.* Vendors often charge significant sums to program machines to read new ballots for each election. For instance, Diebold, in its Iowa Bid, proposed charging counties with ten or fewer precincts $300 per precinct per election. For programming for more than 11 precincts, its charge was $250 per precinct, per election.

Amalgam County, with 59 precincts, would pay a substantial amount to Diebold under this bid. Specifically, it would pay $14,750 per election. With an average of two elections per year, this would amount to an extra $590,000 in costs over 20 years. This is greater than the amount of money Amalgam County would initially pay to purchase any of the PCOS-based systems (all of which should cost less than $500,000 today), and about one-half the initial cost of purchasing a DRE-based system.

Because vendor programming can be so expensive, many jurisdictions have chosen to do their own programming. Doing so can result in substantial savings for jurisdictions with access to a well-trained information technology staff. Of course, the cost of performing programming locally will vary dramatically from county to county depending on such factors as (a) whether appropriately trained personnel are already on staff, (b) the cost of labor in the region, (c) the complexity of the ballots, and (d) whether the jurisdiction is switching to a new system.

It should be noted, however, that jurisdictions that choose to perform their own programming generally pay vendors more for software and maintenance than jurisdictions that allow the vendors to perform the programming. The reasons for this are two-fold. First, many vendors require jurisdictions to license additional software if they are going to perform their own programming. Second, some vendors may charge more for other goods in order to make up for the lost (and repeatable) revenue that they would have received if the jurisdiction had chosen to purchase programming services.

We can see the effect of a jurisdiction performing its own programming on total contract price by looking at side-by-side tables of costs for Amalgam County. In the first column of each table, we look at the total non-programming costs to Amalgam County if the county opts to perform its own programming. In the second column, we look at the total costs if it opts to allow the vendor to perform its programming. *Neither column accounts for the actual cost of programming;* the higher costs in the first column are attributable to higher software license fees.

TABLE C3

SOFTWARE LICENSING FEES FOR PCOS SYSTEM WITH BMD
(COST IN $)

| Year | County does own programming | County does not do own programming |
|---|---|---|
| Initial | 453,624 | 399,263 |
| 5 | 753,642 | 706,867 |
| 10 | 1,057,840 | 987,080 |
| 15 | 1,362,038 | 1,267,293 |
| 20 | 1,666,236 | 1,547,506 |

TABLE C4

SOFTWARE LICENSING FEES FOR PCOS SYSTEM WITH ACCESSIBLE DRE
(COST IN $)

| Year | County does own programming | County does not do own programming |
|---|---|---|
| Initial | 389,867 | 335,506 |
| 5 | 624,139 | 577,363 |
| 10 | 864,932 | 794,172 |
| 15 | 1,105,725 | 1,010,980 |
| 20 | 1,346,518 | 1,227,788 |

TABLE C5

SOFTWARE LICENSING FEES FOR PCOS SYSTEM WITH ACCESSIBLE DRE w/ VVPT (COST IN $)

| Year | County does own programming | County does not do own programming |
|---|---|---|
| Initial | 418,231 | 363,870 |
| 5 | 651,657 | 604,882 |
| 10 | 894,205 | 823,445 |
| 15 | 1,141,160 | 1,046,415 |
| 20 | 1,387,751 | 1,269,021 |

TABLE C6

SOFTWARE LICENSING FEES FOR DRE SYSTEM (COST IN $)

| Year | County does own programming | County does not do own programming |
|---|---|---|
| Initial | 1,027,246 | 972,885 |
| 5 | 1,196,930 | 1,150,155 |
| 10 | 1,407,206 | 1,336,446 |
| 15 | 1,622,532 | 1,527,787 |
| 20 | 1,783,063 | 1,664,333 |

Jurisdictions should consider these extra vendor charges when determining whether to perform their own programming.

### TRAINING

To the extent that a jurisdiction is purchasing an entirely new system from a new vendor, it is likely to have substantial initial training and labor costs.[56] Four major vendors sent election staff training bids to Iowa in 2005.[57] Prices ranged from $715 per worker per day to $2,440 per worker for a two-day course.[58] These charges were the same on a per-worker basis, regardless of the voting system purchased. In general, the training costs should decrease over time: trained, experienced workers should be able train new workers without the need to use vendor-sponsored training. Also, many of the Contracts and Bids included some amount of initial training from the vendor at no additional cost to the jurisdiction.

The case studies, *infra* pp. 151–154, detail some of the additional training costs associated with the purchase of a new system that many election officials cited in Follow-Up Interviews, including: (a) rewriting instruction and training materials for poll workers and employees; (b) rewriting and training employees and poll

workers in new Election Day protocols, (c) teaching employees and poll workers how to replace machine parts when they break down, and (d) training poll workers how to test machines before and after Election Day.

### TRANSPORTATION AND STORAGE

Perhaps more than any other category, transportation and storage costs are going to vary widely by jurisdiction. Many jurisdictions will be able to obtain storage for their systems free of charge.[59] In some cases, there will be no cost for transportation of machines because the distance between polling places and off-site storage is minimal.[60]

On the other hand, some jurisdictions will incur significant costs for storage and transportation. Cass County, North Dakota, which uses a PCOS-based system and owns 56 ES&S M100s reported that in two elections in 2004, it spent $9,292.05 for transportation of its machines, and that it expected storage of these machines (plus its BMDs) to cost about $15,000 per year.[61]

Another western county, which requested anonymity, reported that it used 350 Sequoia AVC Edge DREs in the November 2004 election. This county has approximately the same number of voters as Cass County, but twice the number of precincts. It estimates that it spent $4,500 on transportation of its 350 DREs per election and that it cost $36,000 per year to store them.[62]

We can see how much more Amalgam County might have to pay for its voting systems over time by adding $9,000 per year for transportation and $25,000 per year for storage.

FIGURE C13

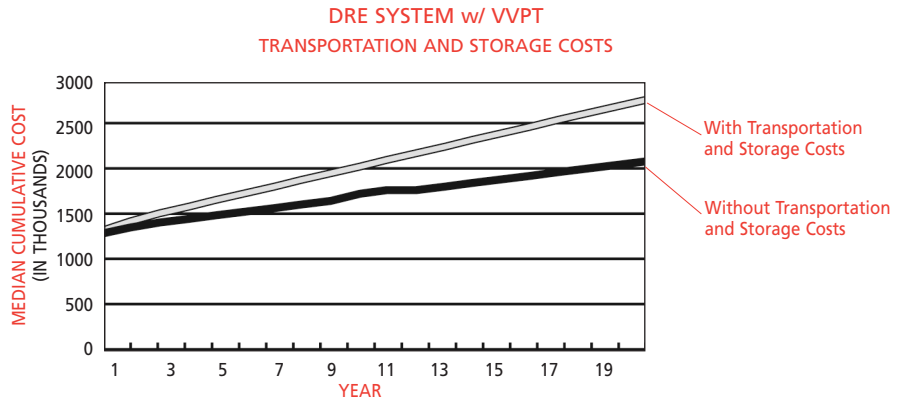
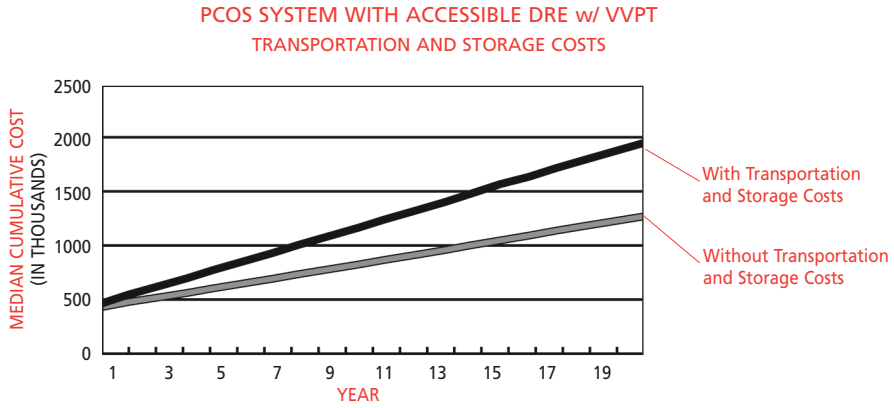


FIGURE C14




As already discussed, a jurisdiction with large precincts is going to need to purchase more DREs than PCOS machines. This could result in greater storage and transportation costs for DRE-based systems than PCOS-based systems.

But there are other, quite significant factors that may play a role in total cost for transportation and storage. Some of these favor DRE-based systems. Some factors that jurisdictions should be aware of when considering potential costs of storing and transporting their voting systems are:[63]

- Paper records (including ballots) may have to be stored in fire-resistant containers.
- For auditing purposes, memory cards (necessary to all Five Voting Systems) may have to be stored.
- DRE-based systems will frequently have Precinct Control Units and Supervisor Terminals which must be stored and transported.
- Consumables, including ink cartridges, pens, and thermal paper may have to be stored.

Some questions that jurisdictions should ask when considering the potential cost of storing and transporting their machines are:[64]

- Do the machines or other system components require storage in climate control?
- Do the machines' batteries require regular recharging?
- What procedures need to be followed in moving units between their storage and polling sites?
- Can damage done to machines during transportation be billed back to companies handling the transportation?

- What system was previously owned? How similar are new machines to previous machines in size, shape, and number?

- Will warehouses or vans previously used for storage and transportation need to be retrofitted to hold new machines?

In Appendix E, we look at the height and weight of some of the most popular DRE, DRE w/ VVPT, and PCOS machines. This information should be useful in assisting jurisdictions to determine what kind of moving and storage costs will be associated with each new system.

In "Case Studies: Purchasing a New System" below, we provide case studies that detail issues jurisdictions have faced when changing voting systems, including additional unexpected costs associated with storage and transportation. Jurisdictions have reported significant costs associated with re-wiring warehouses. (Rewiring has tended to be more of an issue with DREs, which must be periodically recharged; however, if jurisdictions want to test machines in their warehouses, they must have electrical outlets, no matter which system they purchase.) Moreover, because all Five Voting Systems tend to be more delicate than older punch-card or lever machines, counties purchasing one of the Five Voting Systems are often forced to hire and pay for moving companies to ship machines between off-site warehouses and polling places for the first time.

## CASE STUDIES: PURCHASING A NEW SYSTEM

The case studies below[65] are representative of discussions we had with dozens of election officials in our Follow-Up Interviews. Purchasing and converting to a new voting system is expensive. This expense is often independent of what is charged by a vendor. Election officials should consider whether they will need to find new ways of moving their machines, convert current warehouse space, and modify polling places. These and other cost issues are discussed in the case studies.

### CASE STUDY I: TRANSITION FROM PUNCH CARD TO DRE TO DRE w/ VVPT[66]

San Bernardino County, California is home to 750,000 registered voters in 900 precincts. Voting occurs at 410 polling places across the county. The County replaced its punch card system with 4,000 Sequoia Edge 2 DRE machines in 2003, with HAVA and Proposition 41[67] money. The price of the machines was $13.7 million, which included machines and a support warranty through the end of 2005.

Fearing that California might some day require machines to have a VVPT, San Bernardino County negotiated a term that stated Sequoia would add VVPT free of charge if a VVPT became required under the law. In September of 2004, California added a law requiring VVPT for all voting systems. In 2005, Sequoia added the VVPT free of charge, in accordance with the purchase contract. The County has incurred the following costs in implementing its new voting system:

- New Storage Issues. Prior to its purchase of DREs, San Bernardino County stored its voting machines in a single warehouse. Unlike punch card machines, DREs need to be charged regularly. Accordingly, San Bernardino County had to pay to have the warehouse retrofitted to meet the electrical needs of these machines.

- Modifying Polling Places. The County employed teams of 6–10 people to assess whether each of the 410 polling places could accommodate the space and power requirements of the machines. About 35% of the polling places had to be converted or relocated altogether. Residences that had previously served as polling places were especially likely to be inappropriate for DREs because they could not meet the DRE size and power needs.

- New Transportation Costs. With the old punch card system, poll workers would pick up ballots and punch card equipment after training and take them back to their respective polling places. Now, $100,000 is spent on vehicles and labor in order to transport the machines and ballots to the polling places because the machines are so much larger.

- Increased Maintenance. DREs have required more maintenance than the old punch-card systems. The County has experienced frequent component failures. Roughly 80–100 touch screens have required replacement. Batteries have not lasted as long as manufacturers suggested, and about 200 needed to be replaced within two years of purchase. Electronic harnesses and buttons have also failed with some regularity. Replacement touch screens cost $1,500 apiece, and replacement batteries cost $200 apiece. Since the machines are under warranty until the end of 2005, the County has not yet incurred any costs for replacement. However, it has had to pay for labor. Mr. Kouba estimates that when the warranty runs out, San Bernardino County may have to pay as much as $100,000 a year for maintenance.

- Ballot Costs. The county used to spend about $65,000 per election for punch-card paper ballots. Although DREs do not use paper ballots, costs for programming, laying out, and proofing the ballot that appears on the touch screen are substantial. Mr. Kouba estimates they total about $450,000 per election. Ballot-proofing and layout requires the work of four to five people over a period of three weeks. The cost of preparing absentee ballots (San Bernardino uses Optech ballots and OpScan machines for absentee voting) is included in these estimates. Optech ballots are six times the size of old punch-cards ones and take up much more space. In the case of a presidential election, two ballots are needed because of space constraints.

- Preparation for Election. Twenty-five workers, working full time for three weeks, are required to prepare and test the voting machines. Initial training for poll workers and election staff was provided in the purchase contract. Additional support and training from the vendor will have to be purchased separately.

- Post-Election Costs. The County spends between three and four weeks after each election on preventative maintenance to make sure all machines are in good working order. This maintenance involves running diagnostic tests on all machines and repairing any physical problems that arose during the election, such as replacing legs, latches, screens, *etc*.

- Conversion from DRE to DRE w/ VVPT. The County added printers and VVPT in 2005. Mr. Kouba reported that he did not have any major problems with the VVPT in the last 2005 election, although there were increased labor and training costs associated with loading and unloading the paper rolls, and pollworkers experienced some paper jams.

- Security (the Automatic Routine Audit). A manual recount of 1% of the total vote is required by California law as of January 2006 for every election. However, every contest must be included, so 2–3% of ballots or paper rolls are actually audited. DRE results are compared against the paper trail and Optech ballots are handcounted. The automatic routine audit was not instituted at the last election held in San Bernardino County.

### CASE STUDY II: CONVERSION FROM PUNCH CARD TO PCOS[68]

Mendocino County, California is home to 50,713 in 98 precincts. Voting (two elections in even years, one in odd years) occurs at 65–70 polling places across the county. The County replaced its punch-card system with 70 Diebold AccuVote-OS PCOS machines in 2003 with State Proposition 41[69] and HAVA money.

- New Storage Issues. With the purchase of the PCOS System, Mendocino County had to find double the space formerly needed for elections in a County-owned warehouse, including space that was earmarked for other divisions. This space houses the PCOS scanners, voting booths, ballot boxes, and paper ballots. The County does not pay to rent the warehouse space. Before each election, each machine is tested and then charged overnight while still in the warehouse. The warehouse did not have to be retrofitted to accommodate these functions.

- New Transportation Costs. The County has had to hire a moving company, at a cost of $8,000–9,000 per election, to deliver booths and ballot boxes to polling places. The necessary equipment used to be picked up by polling place supervisors and driven to polling places, but the PCOS ballot boxes are too big to continue this practice. Now supervisors pick up (and return) only the Optical Scan unit. For polling places where electronic transmission of results is impossible, the supervisors will typically drive the Optical Scan unit into the County's central office for the results to be uploaded.

- Maintenance. During an early election, the feeding mechanism on some PCOS units became periodically jammed when voters inserted their ballots. When jamming occurred, the ballot had to be cleared out by a poll worker

and reinserted by the voter. The problematic machines were replaced by Diebold after the election at no extra cost. Paper audit rolls and print cartridges must be changed every election, in part because portions are consumed by testing.

- Ballot Cost. Ballot costs per election have increased considerably, from about $5,000 prior to conversion, to at least $30,000 for the current. Over-ordering has also become a concern where it was not before, because whereas punch-card ballots were generic and extras could be retained for future elections, the PCOS ballots currently used are election-specific.

- Training. New duties, such as electronic transmission of results, have required more technology-savvy poll workers. In addition, the county has had to hire Election Day "troubleshooters" to travel between polling places and aid with more difficult technology issues. With each election, fewer troubleshooters have been necessary.

  The county has had to rewrite instructions and training materials, in some cases several times, requiring many hours of election staff time. No voter education was necessary for the conversion to PCOS – it is easier for voters than punch-cards because the layout is more intuitive.

- Preparation for Election. The County requires two employees to test all the machines in the warehouse for two days prior to Election Day.

- Other Costs. The County spends about $200 per election on pens, which were not needed for the punch-card system.

- Unexpected Savings from Conversion. Since PCOS machines tabulate results instantaneously as voters insert their ballots, the County no longer requires personnel to tally results on election night as it did with a punch-card system.

## BRENNAN CENTER FINDINGS

In interviews with the Brennan Center, election officials frequently cited cost as *the* determinative factor when choosing among systems. All too often, however, they did not have sufficient information to understand the full cost implications of purchasing any particular system.

The most important conclusion of this report may be that the challenge of comparing the potential long term costs of particular voting systems is a complicated task that will require detailed investigation and significant guesswork. There are few universal rules. That challenge does not mean that a concerted effort to determine the likely cost of a voting system is pointless. To the contrary, the more information a jurisdiction has, the more likely it will be able to get a clear picture of both the initial and ongoing costs of choosing one voting system over another.

The Brennan Center has posted a "Cost Calculator" online.[70] This Cost Calculator can be used by jurisdictions to perform the kind of analysis for their jurisdiction that we conducted for Amalgam County in this report. In addition to using the Cost Calculator, we urge election officials and concerned citizens to consider four important concepts detailed in this report when examining the potential cost of a particular voting system:

### PURCHASING IN LARGE VOLUME CAN SIGNIFICANTLY REDUCE TOTAL COSTS.

This report shows that vendors offer significant volume discounts, particularly for the initial purchase of hardware. To the extent that counties and states can pool their purchases, they are likely to save considerable money in the purchase of their voting systems. Accordingly, we recommend that states solicit final bids from vendors directly, rather than allowing counties to do so individually. From these final bids, counties can make their own determinations as to which systems and models are best for them.

### THE INITIAL PRICE OF A VOTING SYSTEM WILL FREQUENTLY REPRESENT A SMALL SHARE OF THE TOTAL COST.

Initial costs of information technology systems like voting machines are generally only a small portion of their total, life-span cost. The life-span costs of voting systems will include the purchase and use of consumables like ballots, paper and ink, as well as operating, maintenance and training costs.

As demonstrated in this report, voting systems that initially seem least expensive will often become more expensive than other systems after a few years. Some jurisdictions may decide that, given the constraints of current funding for voting systems and the time value of money, they care most about a voting system's ini-

tial costs. At the very least, they should be aware that, depending upon facts specific to their locations, the costs of the Five Voting Systems are likely to change substantially over time.

## THOROUGH INVESTIGATION IS KEY TO UNDERSTANDING LIKELY TOTAL COSTS.

The total cost of purchasing a voting system will be different for every jurisdiction. We have detailed seven key factors that jurisdictions should consider when attempting to determine the likely, long term costs of voting systems. The Cost Calculator should assist jurisdictions in making that determination.

However, the Cost Calculator cannot supply the answers to many questions that jurisdictions will have to answer to get a complete picture of what a particular voting system may cost them. Among other matters, when purchasing a new voting system, jurisdictions should attempt to determine how much they are likely going to have to pay for ballots, how many ballots they will have to print for each election, how many elections are likely to be held each year, whether they expect significant population growth, how similar the new voting system is to the system they currently use, whether they have trucks and space to accommodate different machines, whether the state pays for transportation, what kind of security measures they are required to take by law, and whether they will have to make changes to warehouse space and polling places to accommodate the new machines.

## ADOPTING A NEW VOTING SYSTEM CARRIES MANY EXPENSES.

As illustrated in our case studies, a repeated lament of election officials was the unexpected costs of adopting an entirely new voting system. These costs are often separate and apart from the amounts charged by a vendor in the voting system contract. They include training poll workers and employees to use, test and maintain the new systems, educating the public on how to use the machines, retrofitting warehouses and polling places to accommodate new machines, and finding new ways of transporting equipment.

Jurisdictions that already use a PCOS- or DRE-based system, in particular, should consider these costs when making determinations about purchasing new machines.

# ENDNOTES

[1] Michael J. Fischer, TrueVote CT, Options for Replacing Connecticut's Voting Machines: A Cost Analysis 8 (Mar. 12, 2005), *available at* http://www.verifiedvoting.org/downloads/CT_Cost-analysis-model.pdf.

[2] New York City Election Voting Systems Department, Electronic Voting Machines – Report on Costs (Draft) (Feb. 2005 – updated Mar. 11, 2005) [hereinafter NYC Electronic Voting Machines Report on Costs].

[3] California Institute of Technology / Michigan Institute of Technology Voting Technology Project, Voting: What is, What Could Be 53 (July 2001), *available at* http://www.vote.caltech.edu/media/documents/july01/July01_VTP_Voting_Report_Entire.pdf

[4] Each of these machines is described in detail in Appendix E.

[5] *See, Voting System Accessibility, supra* p. 39.

[6] A copy of the survey sent may be found in Appendix A.

[7] This assumes jurisdictions record early votes directly on the DRE machines. There will be fewer savings to jurisdictions if early votes are recorded on ballots, for which the jurisdiction must pay.

[8] Election Data Services ("EDS") provided the Brennan Center with the results of one of its voting machines surveys, which purported to show all 324 jurisdictions that had purchased these voting systems since Election Day 2002. In addition to these 324 counties, EDS reported that 11 counties had purchased systems other than the five the Brennan Center analyzed.

[9] Requests were made between July and September 2005. In total, the Brennan Center received 35 contracts or final bids ("Contracts and Bids") executed since November 2002, covering all Five Voting Systems, seven vendors, and ten states. Included among these Contracts and Bids were final bids for the entire states of Iowa, Michigan, and Texas. Copies of the contracts and bids may be found at http://www.brennancenter.org.

[10] A copy of the Follow-Up Survey is included in Appendix B.

[11] *See* Appendix A. Nearly 75 counties provided responses to the Cost Surveys.

[12] The Brennan Center attempted to speak to representatives from each of these vendors: Microvote, Hart, Accupoll, Diebold, Sequoia, and ES&S. For the most part, vendors did not return telephone calls made by Brennan Center employees, or respond to e-mails regarding our study. However, Microvote General Corporation, Accupoll Incorporated, and Sequoia Voting Systems did answer many or all of the questions that the Brennan Center posed. (Notes from interviews on file with the Brennan Center).

[13] The dollar amounts listed in Appendix D are based upon our review of the Contracts and Bids, as well as the responses to our Follow-Up Interviews and Cost Surveys. These costs will vary slightly from jurisdiction to jurisdiction.

[14] Richard Celeste *et al.*, Eds. Asking the Right Questions About Voting Systems 97 (The National Academies Press 2005) *available at* http://www.nap.edu/openbook/0309100240/html/81.html.

[15] *Id.*

[16] For purchasers of DREs w/ VVPT, there is almost always an extra cost for the printers that produce the verified paper trail. The one exception that we have found is the contract between San Diego County, California and Diebold. San Diego purchased several hundred DREs from Diebold in 2002. A May 2004 amendment to the contract specifically provided that if California mandat-

ed VVPT (which it eventually did), Diebold would have to provide and retrofit the VVPT printers free of charge. San Diego's County Supervisor attributes this exceptional deal to the fact that San Diego is a very large county, which gave it greater negotiating power than most counties (and many states) would have. Telephone interview with Ray Chalupsky, Senior Contracting Procurement Officer, San Diego County, California (Oct. 2, 2005).

17 Telephone Interviews with Alan Glover, Clerk-Recorder, Carson City, Nevada (Jan. 17, 2006) and Harvard L. Lomax, Registrar of Voters, Clark County, Nevada (Jan. 30, 2006).

18 *Iowa HAVA Voting Systems Master Contract Pricing List* 6, May 16, 2005, *at* http://www.sos.state.ia.us/pdfs/elections/hava/VotingSystemMasterContractPricingList.pdf [hereinafter Iowa Pricing List]; *Texas Building & Procurement Commission Term Contract*, *at* http://www.tbpc.state.tx.us/cat_page/cat_578_n1_0503.html [hereinafter TBPC Contract].

19 Iowa Pricing List, *supra* note 18, at 7.

20 TBPC Contract, *supra* note 18.

21 *Id.*

22 Copies of the Arizona contracts can be found at http://www.brennancenter.org.

23 Iowa Pricing List, *supra* note 18, at 22.

24 TBPC Contract, *supra* note 18.

25 Copies of the San Diego County contract may be found at http://www.brennancenter.org. San Diego County received another significant savings from Diebold: Diebold agreed to provide San Diego with DRE voter-verified printers for free if California instituted a law requiring voter-verified paper trails. California passed such a law in September 2004, requiring VVPT by the June 2006 primaries.

26 Copies of these contracts can be found at http://www.brennancenter.org.

27 TBPC Contract, *supra* note 18.

28 This estimate assumes that the three counties would pay their voting system vendor to program their machines.

29 A full list of the assumptions made to create these graphs may be found in Appendix C.

30 In approximating the long-term cost of PCOS-based systems, we use information provided from Curry and McLeod counties regarding the average price they paid for PCOS ballots (92 cents and 7 cents per ballot, respectively). We estimated that Lyon County, which uses a DRE-based system, would pay 30 cents per ballot; this is the average price for PCOS ballots paid by respondents to the Cost Surveys.

31 Specifically, the likely cost of training, transportation, and storage is going to depend on such matters as what system the county previously owned, whether it currently has trucks and space to accommodate different machines, whether the state pays for transportation, what kind of security measures the county is required to take by law, *etc*. While each of the three counties was able to provide information regarding costs that it incurred for these items for its *current* systems, determining the potential costs for each of the other four systems would have required the jurisdictions to conduct extensive investigations, solicit bids from vendors, and determine whether, and to what extent, resources currently used in maintaining voting systems could be diverted to new voting systems without significant cost. We did not ask jurisdictions to perform this analysis.

32 Telephone interview with Cindy Schultz, County Auditor, McLeod County, Minnesota (Feb. 3, 2006).

33 For instance, on Election Day in November 2004, a single PCOS machine in East Lyme, Connecticut recorded 3,424 votes. Telephone interview with Carol Marelli, Registrar of Voters,

Town of East Lyme, Connecticut (Oct. 19, 2005).

34 *See* Appendix D for the range of prices charged for hardware, software, and consumables for each system.

35 Among the 110 DREs purchased, at least 16 would have to be "accessible DREs," in order to comply with HAVA's accessibility requirements. The median cost of accessible DREs is slightly higher than DREs, at about $3400. *Id.*

36 Telephone interview with Coni Jo Lyman, Chief Deputy Clerk, Curry County, New Mexico (Feb. 6, 2006).

37 Specifically, we estimate that for Curry County, the median initial price for (1) a PCOS System with accessible DRE would be $372,482, (2) a DRE System (with accessible units) would be $432,589 and (3) a PCOS System with BMD would be $439,036.

38 Cindy Schultz, *supra* note 32.

39 *Id.;* Coni Jo Lyman, *supra* note 36. We do not know the reason for this discrepancy between what Curry and McLeod counties pay for ballots.

40 Lyon County, Kansas has 300–500 absentee ballots a year. Telephone interview with Karen Hartenbower, County Clerk, Lyon County, Kansas (Feb. 3, 2006). Curry County, New Mexico has 1,400 absentee ballots a year. Coni Jo Lyman, *supra* note 36. McLeod County, Minnesota has 200 absentee ballots a year in primaries and 450 in the general election. Cindy Schultz, *supra* note 32.

41 Karen Hartenbower, *supra* note 40; Coni Jo Lyman, *supra* note 36.

42 We determined the average number by looking at the nationwide averages of registered voters, polling places, and precincts from the data tables of the EAC 2004 Election Day Survey. Kimball Brace and Michael McDonald, FINAL REPORT OF THE 2004 ELECTION DAY SURVEY, EAC Survey Analysis Support – EAC 0524, (Sept. 27, 2005), a*vailable at* http://www.eac.gov/election_survey_2004/statedata/StateLevelSummary.htm [hereinafter EAC Survey].

43 As a result, our projections for the cost of the Five Voting Systems are necessarily and artificially low.

44 Because BMDs are a relatively new technology, we were only able to obtain and review Contracts and Bids for ES&S's BMD, the "Automark." In its 2005 Iowa Bid, ES&S offered a "break/fix depot repair" program for $100 per PCOS machine, and a "preventative maintenance" program for $195. For its DRE, it offered a $55 "break/fix" program per machine and a $95 "preventative maintenance" program. For the Automark, it offered a $145 "break/fix" program and a $280 "preventative maintenance" program. Iowa Pricing List, *supra* note 18, at 12, 14–15.

45 Telephone interview with Scott Burnham, Communications Director, Cook County, Illinois (Oct. 30, 2005).

46 E-mail from Howard Cramer, Vice President of Sales, Sequoia (Oct. 21, 2005) (on file with the Brennan Center).

47 Scott Burnham, *supra* note 45.

48 This assumes the county conducts early voting directly on the DRE, as opposed to by ballot.

49 Data tables of the EAC Survey, *supra* note 42.

50 On Nov. 12, 2002, Chambers County purchased 58 DREs for 18,424 registered voters. Telephone Interview with Alicia Moreno, Deputy Voter Registrar, Office of Tax Assessor-Collector, Chambers County, Texas (March, 28, 2006).

51 For instance, in considering a conversion to a PCOS-based system from a DRE-based system, Miami-Dade County, Florida, assumed that it would print its own ballots. It believed doing so

would result in substantial savings to the county. Telephone interview with Lester Sola, Supervisor of Elections, Miami-Dade County, Florida (Dec. 19, 2005).

[52] McLeod County, Minnesota has 1 election per year. Cindy Schultz, *supra* note 32.

[53] Curry County, New Mexico has 4–5 elections per year. Coni Jo Lyman, *supra* note 36.

[54] This analysis may overestimate the cost of ballots. It assumes that counties would purchase the same number of ballots for all elections, regardless of whether they were general, primary, municipal, or special elections. In fact, counties may purchase fewer ballots for primary, municipal, and special elections than they do for general elections; the cost of these ballots for off-year elections and primaries may also be lower because the ballots may be less complicated.

[55] Ramona Doebler, Auditor/Treasurer, Sherburne County, Minnesota (Sept. 23, 2005) (Response to Cost Survey, on file with the Brennan Center).

[56] Some jurisdictions purchasing new systems will have already used an older version of PCOS or DRE. For these purchasers, there are likely to be significant cost savings in remaining with a new version of the same system. These savings will most likely manifest themselves in the areas of training and programming. In addition, the jurisdiction will probably have to spend less time educating voters. Staying with a system could also mean that the jurisdiction has to buy fewer machines – presumably if voters are already familiar with a system, more of them will be able to vote on a single machine in a single day.

[57] *See* Iowa Pricing List, *supra* note 18.

[58] *Id* at 26.

[59] For instance, among the many counties that informed us they did not incur costs for storage of machines were Lyon County, Kansas, Eddy County, New Mexico, Ralls County, Missouri, Curry County, New Mexico, and Van Buren County, Iowa. This list includes counties that used both PCOS- and DRE-based systems. Responses to the Cost Surveys are on file with the Brennan Center.

[60] For instance, among the many counties that claimed no money was spent on transportation of machines were St. Clair County, Missouri, Village of West Milwaukee, Wisconsin, Saint Cloud, Minnesota, Humphreys County, Tennessee, Mussellshell County, Montanna, Sheboygan County, Wisconsin, Nemaha County, Kansas, and Oconto County, Wisconsin. This list includes counties that used both PCOS- and DRE-based systems. Responses to the Cost Surveys are on file with the Brennan Center.

[61] Mike Montplaisir, Elections Office, Cass County, North Dakota (Sept. 23, 2005) (Response to the Cost Survey, on file with the Brennan Center).

[62] Interview with County Election Official A (Sept. 9, 2005) (on file with the Brennan Center).

[63] For a more in-depth discussion of these factors, *see* ASKING THE RIGHT QUESTIONS ABOUT VOTING SYSTEMS, *supra* note 14, at 81.

[64] *Id.*

[65] Mr. Kouba and Ms. Wharff were given the opportunity to present their case studies anonymously. Both stated that anonymity was unnecessary.

[66] Interview with Terry Kouba, Chief Deputy Registrar of Voters, San Bernardino County, California (Nov. 29, 2005).

[67] Proposition 41, the Voting Modernization Bond Act of 2002 was approved by the voters at the March 4, 2002 election. It allocates $200 million to upgrade voting systems, and established a Voting Modernization Board to carry out this task.

[68] Interview with Marsha Wharff, Assessor-County Clerk-Recorder, Mendocino County,

California (Nov. 29, 2005).

69 *See supra* note 67.

70 The Cost Calculator may be found at http://www.brennancenter.org. We describe how to use it in Appendix F.

71 We do not have similar life-span information for DREs w/ VVPT or BMDs, both of which are relatively new technologies.

72 Telephone interview with Vada Holstein, Oklahoma State Board of Elections (Dec. 22, 2005).

73 Telephone interview with Brooks Garett-Jones, Election Technician, North Carolina Board of Elections (Nov. 2, 2005).

74 Maintenance agreements are often part of the voting machine contracts. The Brennan Center has posted a number of contracts that include maintenance agreements at http://www.brennancenter.org.

75 NYC Voting Machine Report, *supra* note 2. To the extent that these requirements apply to PCOS machines, they may drive up the machines' initial hardware costs by up to 40%. *Id.*

76 *See* p. 99 of this report.

77 The New York State Board of Elections has taken the position that New York jurisdictions must purchase full-face machines. *See* New York draft regulations Section 6209.2 (A)(1) *available at* http://www.elections.state.ny.us/hava/machine-cert-6209.pdf, http://www.elections.state.ny.us/hava/2ndDraftVotingMachineRegs.pdf. The Brennan Center has disputed this interpretation of New York Law. *See* Brennan Center for Justice at NYU School of Law, *Memorandum to New York State Board of Elections* (Nov. 16, 2005) *available at* http://www.brennancenter.org/presscenter/FFB%20Legal%20Memorandum%20Final.PDF. Delaware also has such a law. *See* DEL. CODE. ANN. tit. 15 § 4501.

78 For instance, California requires precincts to print a number of ballots equal to "not less than 75% of registered voters in the precinct." CAL. ELEC. CODE § 14102(a)(1). Hawaii requires a "sufficient number" of ballots to be printed, based upon the number of registered voters and the expected spoilage in the election. HAW. REV. STAT § 11-119. Massachusetts requires not less than one ballot for each registered voter at each polling place. MASS. GEN. LAWS ch. 54, § 45. North Carolina merely requires "an adequate quantity" to be determined by local officials. N.C. GEN. STAT. §§ 163-165.10. Texas requires an amount equal to "at least the percentage of voters who voted in that precinct in the most recent corresponding election, but not exceeding the total number of registered voters in the precinct." TEX. ELEC. CODE ANN. § 51.005.

79 Telephone interview with Harvard L. Lomax, Registrar of Voters, Clark County, Nevada (Nov. 8, 2005).

APPENDIX A

## BRENNAN CENTER COST SURVEY

Any individuals and jurisdictions referred to in this report are printed with express permission obtained outside of this survey.

### The Brennan Center at NYU School of Law
### Voting Machine Cost Survey

The Brennan Center is currently drafting a voting machine cost report. Among other things, the report is meant to assist election officials in making future voting machine purchases.

The Brennan Center has collected dozens of recently executed voting machine contracts and is currently reviewing them as part of its analysis.

Of course, in addition to costs listed in voting machine contracts, there are often additional costs associated with voting machine purchases. We are hopeful that you can assist us in identifying these costs. Accordingly, we request that you review the questions below and answer them to the best of your ability.

*If you choose, your responses will remain anonymous.* This means that neither you nor your jurisdiction will be identified in the results.

The responses can be returned by fax to Lawrence Norden at 212-995-4550 or by e-mail at Lawrence.Norden@nyu.edu. Thank you for your help with this very important project.

1. Do you request that your responses remain anonymous?
   ❑ yes ❑ not necessary

2. What type of machine(s) did you use in the last election (please indicate make, model and type)?

3. How many of each type of machine are used in your county in general elections?

4. When were these machines purchased?

5. How many registered voters are there in your county?

6. How many precincts are there in your county?

7. Are there any transportation costs associated with the movement of your voting machines on Election Day? If so, what were these costs? How much was spent on transportation of voting machines on each of the last four (4) elections (please provide dates and amount spent)?

8. Are there any storage costs associated with your voting machines? If so, how much is spent per year on storing your voting machines?

9. Did you incur any costs for training in excess of what is provided for in your voting machine contract? If so, how much has been spent in each of the last five (5) years (if possible, please breakdown expenses by type of training – *e.g.*, poll worker training, program training, *etc.*)?

10. Did you incur any costs for programming in excess of what is provided for in your voting machine contract? If so, how much has been spent in each of the last five (5) years?

11. Did you incur any costs for maintenance in excess of what is provided for in your voting machine contract? If so, how much has been spent in each of the last five (5) years?

12. If you use PCOS machines, what is the approximate cost of ballots, including printing (cents per ballot)?

13. Can you identify any other costs associated with your voting machines that were not covered in your voting machine contract (*e.g.*, electricity to recharge machines, purchase of replacement parts)? If so, please list each of those items and the amount of associated costs on a per year basis (if you use more than one type of machine, please break down additional costs by type of machine – *e.g.*., $300 per 5 years for memory card replacement for PCOS, $500 per year for memory card replacement for DRE).

    Battery replacement? _____ Approximate cost per year? _____

    Memory card replacement? _____ Approximate cost per year? _____

    Other replacement? (please identify) _____ Approximate cost per year? _____

    Electricity/Recharge cost? _____

    Other costs? (please identify) _____

14. Do you have either (a) a depreciation formula for your machines, or (b) an estimate of how long you expect your voting machines to last before they will need to be replaced? If yes to either (a) or (b), please provide details.

15. The Brennan Center would like to use certain counties as case studies in its report. The purpose would be to show future voting machine purchasers the types of extra costs that might be associated with purchasing a particular voting system. The individuals and jurisdictions used as case studies will remain anonymous in the Brennan Center Report. Would you object to our contacting you to participate as an anonymous case study?

County, State: _____

Name/Title: _____

Phone/e-mail: _____

Best time to follow up: _____

## APPENDIX B

# BRENNAN CENTER FOLLOW-UP SURVEY

1. What type of machine(s) did you use in the last election (please indicate make, model and type)? When were these machines purchased?

   How many registered voters are there in your county?

2. How many precincts are there in your county?

3. Are there any transportation costs associated with the movement of your voting machines on Election Day? If so, what were these costs? How much was spent on transportation of voting machines on each of the last four (4) elections (please provide dates and amount spent)?

4. Are there any storage costs associated with your voting machines? If so, how much is spent per year on storing your voting machines?

5. Did you incur any costs for training in excess of what is provided for in your voting machine contract? If so, how much has been spent in each of the last five (5) years?

6. Did you incur any costs for programming in excess of what is provided for in your voting machine contract? If so, how much has been spent in each of the last five (5) years?

7. Did you incur any costs for maintenance in excess of what is provided for in your voting machine contract? If so, how much has been spent in each of the last five (5) years?

8. If you use PCOS machines, what is the approximate cost of ballots (including printing)?

9. Can you identify any other costs associated with your voting machines that were not covered in your voting machine contract (*e.g.*, electricity to recharge machines, purchase of replacement parts)? If so, please list each of those items and the amount of associated costs on a per year basis.

   Battery replacement? _____ Approximate cost per year? _____

   Memory card replacement? _____ Approximate cost per year? _____

   Other replacement? (please identify) _____ Approximate cost per year? _____

   Electricity/Recharge cost? _____

   Other costs? (please identify) _____

10. Unexpected costs associated with machines?

11. If making the purchase over again, what are things you would want to know about system that you didn't?

12. (For PCOS) – what kind of costs are associated with paper?

APPENDIX C

# ASSUMPTIONS IN DETAIL

## LIFE SPAN AND REPAIR

In estimating the cost of systems, we have assumed that the life span of each system will be exactly the same. This is almost certainly untrue both among and within systems (some vendors' products are likely to last longer than others, even within the same system). The Brennan Center did not obtain enough information on each of the systems to comment on their likely life spans. However, both DRE and PCOS machines have been used without major replacements in a number of jurisdictions for more than ten years.[71] For instance, every county in Oklahoma has used a version of the PCOS system since 1992.[72] And Macon County, North Carolina has used a version of the DRE since 1986, without needing to replace any major parts.[73]

The Brennan Center was not able to obtain enough information about repairs to different voting systems to estimate actual, annual, out-of-pocket repair costs for each system. However, most vendors offer up-front maintenance agreements for their machines. We assumed that jurisdictions will enter into these maintenance agreements. We further assumed that vendors and jurisdictions would renew these maintenance agreements for the life of the machines. For the most part, the maintenance agreements cover replacement of hardware (but no consumables such as batteries and removable memory cards) to the extent necessary to ensure that machines will work "substantially as described" in the voting machine contracts.[74]

## CONGLOMERATION OF MACHINE TYPE

Each vendor manufactures slightly different versions of DREs, DREs w/ VVPT and PCOS, and in many cases a single vendor may manufacture more than one version of the same type of machine. We have not distinguished between vendor, and our cost estimates are based on the median price charged for hardware, software, and consumable goods for each type of system.

Our discussion of the cost of DRE-based systems is limited to systems that use "scrolling" DREs (each race appears on the DRE screen separately; after the voter makes her selection for the first race, the second race will appear on the screen), as opposed to "full-face" DREs (all candidates and races listed on a single screen). All of the Contracts and Bids we reviewed listed prices for "scrolling" DREs only.

The initial hardware costs for scrolling DREs can be less than half the cost of full-face DREs.[75] Moreover, full-face machines have been shown to produce high-

er rates of residual voting.[76] Given these facts, we believe very few jurisdictions will purchase full-face machines.[77]

## INFLATION, TIME VALUE OF MONEY

In projecting costs over time, we have assumed there will be no increase in licensing, maintenance fees or the purchase price for consumables or replacement parts. While such costs are likely to increase over time, we cannot project by what amount, or for which system the rate of increase might be greater.

Furthermore, we have computed total costs without considering the "time value" of money. Jurisdictions may determine that they would prefer to spend less money initially, even if it means spending more in total dollars over 20 years. Our purpose is not to make this judgment for localities; it is only to point out the potential short- and long-term costs of each voting system.

## NUMBER OF BALLOTS PURCHASED

We have assumed that jurisdictions using PCOS machines will purchase ballots equal to 100% of the number of registered voters; this assumption includes the printing of both absentee and polling place ballots. We have assumed this is true for *all* elections, regardless of whether the election is primary or general, presidential or mid-term. In fact, laws on the number of ballots that must be printed vary drastically from state to state.[78]

## GROWTH/CHANGES IN JURISDICTION

In estimating and projecting the overall cost of voting systems, we have not factored in the costs that may be incurred as a result of population or political changes in the jurisdiction.

An increase in a jurisdiction's population may make DRE-based systems relatively more expensive over time, in a way that is not reflected in this analysis. For instance, Clark County, Nevada, one of the fastest growing counties in the country, first purchased DREs in the early 1990s. Since that time, it has repeatedly had to purchase additional machines to accommodate additional voters.[79] PCOS scanners can handle many more voters in a day than a single DRE machine. In a jurisdiction that used a PCOS-based system and experienced rapid population growth, it might not be necessary to buy any new machines.

On the other hand, a decision to create new precincts (perhaps because of a growth in population, or other political considerations) is likely to increase the number of PCOS scanners that jurisdictions will have to purchase. Our analysis does not detail how this kind of political change would affect the cost of PCOS based systems. It is significantly easier to put multiple precincts on a single DRE machine than on a single PCOS scanner.

## OTHER COSTS

Our "Analysis of Total Cost" is very likely to underestimate the ongoing operating costs of all Five Voting Systems. There are literally hundreds of costs associated with operating, maintaining, and using a voting system. These costs include everything from preparing public education materials on how to use voting machines to purchasing the machines themselves. Our analysis includes what we have concluded to be the biggest cost factors in purchasing, operating, maintaining, and using the voting systems. These factors are likely to have the greatest impact in determining the total cost of a voting system, and in making one system more or less expensive than another.

APPENDIX D

# LIST OF COSTS FOR EACH VOTING MACHINE

| | INITIAL | OPERATING |
|---|---|---|
| **Hardware** | | |
| PCOS | Scanner ($4,500-6,000) | Memory card ($75-250) |
| DRE | DRE Unit ($2,100-3,700)<br>Supervisor Terminal ($2,200-2,800)<br>Precinct Control Unit ($600-2,500)<br>Precinct Printer ($600-800)[1] | Memory card ($60-150) |
| Accessible DRE | Accessible DRE unit ($2,800-$3,800) | Headphones ($15) |
| DRE w/ VVPT | Same as DRE, plus:<br>VVPT Printer ($02-1,000) | Memory card ($60-150) |
| BMD | BMD Unit ($5,000-5,400) | Memory card ($90)<br>Headphones ($15) |
| **Software** | | |
| PCOS | Election Management System ("EMS") (varies according to county size) | EMS license (varies according to county size)<br>Firmware license ($25-100 per precinct per year) |
| DRE | EMS | EMS license<br>Firmware license ($20-100 per precinct per year) |
| Accessible DRE | Same as DRE | Same as DRE |
| DRE w/ VVPT | Same as DRE | Same as DRE |
| BMD | Same as DRE, plus:<br>AIMS software ($2,500 initial cost) | Firmware license ($30 per polling place per year) |
| **Consumables**[3] | | |
| PCOS | Pens (for ballots) ($0.50/ea) | Ballots ($0.22-0.30)<br>Pens<br>Paper for tally and audit trail ($1-5/roll, 1-3 rolls per machine per election) |
| DRE | | Thermal paper for tally reports ($2-4/roll, 1 roll per machine per election) |
| Accessible DRE | | Same as DRE, plus:<br>Headset ear covers ($0.15/set, 1 set per voter) |

| | INITIAL | OPERATING |
|---|---|---|
| DRE w/ VVPT | | Printer paper ($1-5/roll, about 3 rolls per machine per election)<br>Printer ink ($6-30 per machine per election)<br>Thermal paper (same as DRE) |
| BMD | | Ink cartridge ($25-30 per polling place per election)<br>Thermal paper ($2/roll, 1 roll per machine per election)<br>Headset ear covers ($0.15/set, 1 set per voter)<br>Cardboard secrecy sleeves ($2.50/ea, 1+ per simultaneous voter) |
| Other | | |
| PCOS | Installation ($50-100/machine)<br>Training/testing ($90-200/hr)<br>Election support ($90-250/hr) | Training<br>Election support<br>Storage |
| DRE | Programming<br>($250-1,500/machine per election) | Programming<br>Maintenance agreement ($100-250/machine per year)<br>Archiving of ballots |
| Accessible DRE | Programming ($250-300/machine per election) | Maintenance agreement payments ($85-230/machine per year) |
| DRE w/ VVPT | Same as DRE | Same as DRE |
| BMD | Installation ($60-105 per machine, if jurisdiction cannot install their own) | Maintenance agreement payments ($145-280 per machine per year)<br>Archiving of ballots |

[1]Implementations of ballot activation equipment vary by vendors. Many (e.g. Diebold, Accupoll, Unilect, and Hart) require a Precinct Control Unit ("PCU") (essentially a PC or laptops) at each precinct, the cost of which usually includes either a "electronic ballot" activator, a printer (to print a unique code a voter activates a DRE with), or both. Other vendors (e.g. Microvote and Sequoia) require only that a card activator device be purchased for each precinct. For ES&S systems, the number of Supervisor Terminals depends upon whether the county uses a poll worker- or voter-activated ballot system. For the former, the Supervisor Terminal is required only to activate supervisor Personal Electronic Ballots ("PEBs") for poll workers. For a voter-activated implementation, a Supervisor Terminal is required for every precinct, so that a poll worker can load a ballot onto a PEB for each voter.

[2] Accupoll builds VVPT into every DRE machine.

[3] Initial consumable items generally included with PCU, printer pack, or other mandatory item.

## APPENDIX E
# VOTING MACHINE DIMENSIONS

| Type & Model | Dimensions | Weight | Charging Time | Climate-controlled Storage Required? |
|---|---|---|---|---|
| **DRE** | | | | |
| Hart InterCivic eSlate[1] | 11"x17"x3" | 28 lbs w/ booth | non-rechargable battery lasts 18 hrs | No |
| Sequoia AVC Edge[2] | 26"x17"x10" | 38-40 lbs | N/A | N/A |
| ES&S i Votronic [3] | 16.1"x18.5" | 14.35 libs x2.65" | charge overnight before elections + every 3 months when not in use | No |
| Diebold AccuVote-TS[4] | 15"X19"x3" | 29 lbs | 3hrs | Yes |
| Diebold AccuVote TSX[5] | 15"x19"x3" | 29 lbs | 3hrs | Yes |
| AVS WinVote[6] | 14" x 16"X3" | 23 lbs | Runs on standard 110-volt electricity, has a self-contained 3 hr battery | Yes |
| Unilect Patriot[7] | 17 x 15"x2.2" | 5-8 lbs | runs on electrical power, backup battery should be allowed to charge continuously between elections | No |
| **DRE w/ VVPT** | | | | |
| AccuPoll [8] | 24"x20"x13" | 36 lbs | info not available | N/A |
| AvanteVote-Trakker EVC-308SPR[9] | 20"x20"x20" | 18 lbs | leave plugged in at all times | No |
| **PCOS** | | | | |
| Avante Optical Vote Trakker[10] | 18"x18"x12" | 30-35 lbs | keep plugged in at all times to maintain charge | No |
| ES&S Model 100[11] | 5"x14"x16" | 20.7 lbs | Charge overnight before elections + once every 6 months when not in use | No |
| Sequoia Opteck Insight[12] | 17.5x19"x22.5" | 25 lbs | N/A | N/A |
| Diebold AccuVote-OS[13] | 14x16"x3" | 15 lbs | Overnight | Yes |
| **BMD** | | | | |
| ES&S Automark[14] | 17.6x26x20.8" | 39 lbs | N/A | N/A |
| Populex[15] | 17.5"x17.5" | >15 lbs | N/A | N/A |

1 http://www.capc.umd.edu/rpts/md_evote_ContempVotingMach.pdf (dimensions); http://www.hartic.com (weight); Telephone interview with Hart InterCivic employee (April 21, 2006) (charging time and storage requirements).

2 http://www.sequoiavote.com/productguide.php?product=AVC%20Edge&type=Specifications

3 http://www.essvote.com/HTML/products/ivotronic.html, http://www.capc.umd.edu/rpts/md_evote _ContempVotingMach.pdf

4 Telephone Interview with Diebold employee (April 20, 2006 ).

5 http://www.diebold.com/dieboldes/accuvote_tsx.htm.

6 http://www.uhavavote.org/vendorfair/survey_results/AVS.doc.

7 http://www.capc.umd.edu/rpts/md_evote_ContempVotingMach.pdf, weight: http://www.unilect.com.

8 http://www.votingindustry.com/TabulationVendors/2ndtier/Accupoll/accupoll.pdf.

9 http://www.capc.umd.edu/rpts/md_evote_ContempVotingMach.pdf.

10 Telephone Interview with Avante employee (April 20, 2006 ).

11 http://www.capc.umd.edu/rpts/md_evote_ContempVotingMach.pdf.

12 http://www.sequoiavote.com/productguide.php?product=INSIGHT&type=Specifications.

13 http://www.capc.umd.edu/rpts/md_evote_ContempVotingMach.pdf.

14 http://www.essvote.com/HTML/docs/AutoMark.pdf.

15 http://www.populex.com/DPB_Overview.htm.

APPENDIX F

# EXPLANATION OF THE COST CALCULATOR

## HOW TO USE IT

The Cost Calculator can serve several purposes for election officials and concerned citizens.

First, by permitting users to tailor their input to match the actual conditions of their jurisdictions, the calculator allows users to understand what initial and long term costs associated with a particular system might be. They can use the calculator to compare the potential costs for each system. As noted above, many of these costs are not necessarily spelled out by bids or contracts that jurisdictions negotiate or receive.

For instance, in addition to initial hardware and software costs, purchasers are likely going to have ongoing costs for software licensing fees and maintenance, as well as for consumables like pens, printer ribbons, paper, and ballots. The calculator will approximate these costs over a period of time (fixed by the user).

Second, the Cost Calculator also allows users to understand how certain decisions could lead to a change in contract prices. For example, a jurisdiction's decision to program its own machines will (not surprisingly) lead to a smaller total charge from most vendors because the jurisdictions will avoid programming charges from the vendors. However, we have found that jurisdictions that do their own programming are also likely to be charged slightly more for software and software maintenance. Thus, the savings for doing their own programming might not be as large as some jurisdictions would expect.

Third, the Cost Calculator allows officials to understand both the potential initial and ongoing costs of purchasing a particular system. Using this information, they should get a handle on whether their HAVA and other funding will allow them to purchase the number of machines necessary to accommodate their jurisdiction's size, and what long term costs they are taking on by purchasing one system over another.

Finally, even where a jurisdiction has determined which voting system it would like to purchase, the Cost Calculator should tell it whether it has received a fair bid from vendors (at least compared to deals struck by states and counties between 2002 and 2005). The Cost Calculator should also give members of the public greater confidence that their election officials negotiated the best deal possible for their county or state.

## CALCULATOR LIMITS

Most significantly, the Cost Calculator generates its estimates based on the median prices charged in a limited set of contracts. The Cost Calculator output is

based upon contract and bid prices from between 2002 and the present. This information is likely to change in a short amount of time. Costs of new technology (which particularly includes BMDs, DREs, and DREs w/VVPT) are most likely to fluctuate in the short term.

Moreover, while the Cost Calculator attempts to assist jurisdictions in determining total costs of purchasing a voting system over a fixed period of time, it does not allow users to determine how a change in population might affect costs over the long term. For instance, Clark County, Nevada, one of the fastest growing counties in the country, first purchased DREs in the early 1990s. Since that time, they have repeatedly had to purchase additional machines to accommodate additional voters.xi The calculator would not allow Clark County to determine to what extent growing population would affect its long term costs under each voting system.

There are other reasons the estimates given by the Cost Calculator are necessarily limited in scope. The data from the contracts collected by the Brennan Center are most consistent as they relate to initial hardware purchases and hardware maintenance agreements, because nearly every contract or estimate included these items in a well-defined form. For these costs, the Cost Calculator does not include any extras, backups, or alternative systems (i.e. ballot-scanning systems to count provisional or absentee ballots or to serve as fail safes for a DRE-based implementation) that many counties choose to purchase. Other costs were more difficult to model, and have been addressed in a variety of ways.

Software costs were one such area. Some vendors, such as Diebold and Accuvote, provided in their estimates graduated cost schedules for their election management system ("EMS") software, so that it is a trivial matter to calculate the software costs given the number of precincts in a county. Others, however, appear to negotiate EMS costs on a contract-by-contract basis according to no discernible system. Still others (such as Microvote) seem to charge a relatively fixed cost for their software, regardless of the size of the county. Every vendor charges a premium to counties who wish to program the hardware on their own, as opposed to purchasing programming services from the vendor. The EMS calculator tool on the input form represented a best guess averaging data from four vendors' (ES&S, Diebold, Microvote and Accupoll) contracts. However, the user may also input a different cost than the one calculated. The Cost Calculator is likely to underestimate EMS costs for very large jurisdictions, and overestimate EMS costs for small purchases made by very small jurisdictions.

Training, installation, support, and voter awareness services are also difficult to calculate based upon available data. A county's need for these services is largely a function of not only the size of the county, but on its existing infrastructure, the savvy of its employees, poll workers and voters, and other factors. Several of the contracts listed hourly or daily rates for these services, but the totality of the data did not yield a formula for determining these needs according to a county's size. The Cost Calculator is incapable of evaluating these variables.

Finally, neither the Cost Calculator nor this report addresses the cost of replacing various systems, or how long each system can be expected to last. Some data that may help voting machine purchasers assess these factors may be found in this report.

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