CALTECH VTP MIT
VOTING TECHNOLOGY PROJECT

Voting

What Is
What Could Be

The Caltech/MIT Voting Technology Project came into being while the ballot battles of the 2000 presidential election were still being fought in Florida. The California Institute of Technology and the Massachusetts Institute of Technology saw a need for strong academic guidance in this intersection of technology with democracy. As the presidents of these two Institutes, we are proud to have mobilized a team of computer scientists, human factors engineers, mechanical engineers, and social scientists to respond to this national need. We are extremely grateful to the Carnegie Corporation of New York for responding so quickly to our request for support for this project.

The Voting Technology Project team began its research with a desire to evaluate existing voting technologies to determine whether they meet the country's needs for a secure, reliable, robust system of recording election preferences. The team also saw a need to understand how machine performance and reliability fit into the larger picture of election administration. Caltech and MIT researchers collected data from around the country and met with leading election officials, researchers, and industry representatives. We are grateful to everyone who contributed wisdom and data to our this research effort.

It is evident that problems with counting the votes of the citizens of Florida and elsewhere originated in unsound technology. In the last election, Americans learned that at the heart of their democratic process, their "can-do" spirit has "make-do" technology as its central element. For many years, we have "made do" with a this deeply flawed system, but we now know how poorly these systems function. Until every effort has been made to insure that each vote will be counted, we will have legitimate concerns about embarking on another presidential election.

This report presents the findings of the first six months of research by the Project team. While six months is hardly a sufficient amount of time to solve such a core question of American democracy, the report does provide recommendations both for concrete improvements, which could be made before the next election, and for guidance in setting the direction of future technological innovation. We strongly urge all U.S. officials with a role in the voting process—including members of Congress—to act on the findings of this dispassionate group of technologists and social scientists.

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CALIFORNIA INSTITUTE OF TECHNOLOGY 1891

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Executive Summary and Overview

On December 15, 2000, the California Institute of Technology and the Massachusetts Institute of Technology announced a collaborative project to develop new voting technology in order "to prevent a recurrence of the problems that threatened the 2000 presidential election." The problems in the 2000 election go well beyond voting equipment. This report assesses the magnitude of the problems, their root causes, and how technology can reduce them. We call for a new architecture for voting technology that is tailored to the communication and computing technologies that have revolutionized our society. We also see a new system of continual innovation that can be supported by the federal government.

What Is

Our data show that between 4 and 6 million votes were lost in the 2000 election. Our analysis of the reliability of existing voting technologies and election systems shows that the U.S. can substantially reduce the number of lost votes by immediately taking the following steps:

- Upgrade voting technologies. Replace punch cards and lever machines with optical scanners. We estimate 1.5 million of these lost votes can be recovered with this step.

- Improve voter registration systems. We recommend improved database management, installing technological links to registration databases from polling places, and use of provisional ballots. We estimate this could save another 3 million lost votes. Aggressive use of provisional ballots alone might substantially reduce the number of votes lost due to registration problems.

What Could Be

In the long term, the voting equipment industry will develop new technologies. Our report includes the following recommendations to ensure that the best available technologies are developed by this industry:

- We call for a new architecture for voting technology. This architecture will allow for greater security of electronic voting. It will allow for rapid improvement and deployment of user interfaces—that is, better ballots. It is a framework within which we can explode several myths about electronic voting.

- There must be significant investment by the federal government in research and development of voting equipment technologies and meaningful human testing of machines.

- The federal government should establish an independent agency to oversee testing and to collect and distribute information on the performance and cost of equipment.

Who We Are

The furor over the 2000 presidential election in Florida brought this group together. David Baltimore, the president of the California Institute of Technology, and Charles Vest, the president of the Massachusetts Institute of Technology, assembled our team of computer scientists, mechanical engineers, and social scientists to consider what is and what could be. The Carnegie Corporation sponsored our project.

This report offers our assessment of what works, what does not, and what can be improved in existing voting technology. How big are the problems in voting? What solutions exist today? How can we improve voting for the 2004 presidential election?

Our ultimate goal is to develop ideas about what could be. The United States is in the midst of a revolution in communication and computing technology. That revolution will transform voting in the future. These technologies hold enormous promise—to make voting easy, convenient, and accessible, and to allow voters to see that their votes are counted.

Our team members who drafted this report were:

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In addition to the faculty involved, many students contributed to this project. Darian Unger, Jonathan Goler, and Aaron Strauss provided invaluable assessments of user interface designs. Tara Butterfield, Lee Carpenter, Michelle Nyein, Meena Untawale, James Wagner, and Catherine Wilson helped collect data on public finances, election results, and machine usage in the United States.

Our group was assembled for its expertise, rather than its political leanings. Some of us are Democrats; some of us Republicans; some of us have no partisan leanings or political inclinations.

Two professional staff members have coordinated our activities and made this project happen. We owe a special debt to Julie Brogan, Esq. and Mary King Sikora. Editing assistance was provided by John B. Jacoby.

PART I
WHAT HAS HAPPENED

The Problem

The controversy in Florida exposed two very important problems with the way elections are run in the United States: recounts and system failure.

Recounts

Contested elections happen. In the event of a contested election, candidates can challenge the initial count and request a recount. If there are sufficient problems, especially stolen or fraudulent ballots, the courts may have to resolve the counts or even require a revote.

The Florida recounts demonstrated just how hard it is to determine who won—given the existing means of casting and counting ballots. Some technologies produce particularly poor records of the voters' intentions. The controversy in Florida centered on punch cards. Many votes were lost because voters did not punch the card through entirely or they punched two candidates' names, perhaps by accident. These problems were widely blamed on the voters, though similar voters had fewer problems with other technologies, such as in-precinct optical scanners.

As the challenge in Florida moved first to the election boards and then into the courts, it became evident how very difficult it would be to resolve the count. The technological flaws could not be resolved unambiguously by recounting using the ballot counting machinery. Election officials and judges had to make judgments about what should be counted and how, and then they had to count the ballots anew, by hand. Lacking clear legal standards, votes were not considered and counted the same in different jurisdictions.

Machinery that loses votes is worse than machinery that produces ambiguous records of voter intention. Lever machines and many electronic voting machines provide no record of voters' intentions apart from the count itself. If a machine is broken, say because of a jammed counter or an electrical short, then all votes are lost on that machine. If a sufficient number of votes are lost, the election is thrown into question. The election may also be thrown into doubt if an act of fraud alters or destroys a sufficient number of votes. Then, we may have to conduct the election again.

How common are these problems? How many elections might be affected? How many jurisdictions might be affected?

Close elections, problematic votes, and recounts occur in every election year and in every jurisdiction. In 2000, Florida's presidential votes were recounted, so, too, were U.S. Senate votes in the state of Washington. In the 2000 presidential election, the winner's margin was less that one-half of one-percent in four states: Florida, Iowa, New Mexico, and Wisconsin. Many state legislative contests were recounted as well—for example, three in Colorado. Recounts occur when the margin between the top two vote getters is extremely small. We find that the rate of uncounted and spoiled ballots ranges from two to three percent in presidential contests, depending on the equipment used, and from three to seven percent in Senate and gubernatorial elections, depending, again, on the equipment used. This rate of questionable ballots is high enough to affect numerous contests each year.

The problems observed with specific technologies in the 2000 elections are not new. Following widely publicized problems with punch cards in the 1968 election, IBM withdrew from the election machine business. In 1996, a contested and recounted primary for the Massachusetts 10th Congressional District led that state to abandon punch cards. We now face a similar choice nationwide because of the problems with punch cards in the Florida recounts. Technologies available today can produce better records of the vote than punch cards. These other technologies, while superior, are, nonetheless, imperfect. In order to minimize ambiguous recounts, we need to improve voting equipment.

Contested elections happen. We should prepare for them.

System Failure

Recounts and contested elections aside, it is important to make sure elections work. They are the foundation of our democracy and a model for democracies around the world.

Like most Americans, we took it for granted that election administration worked. Surely, after so many

years of successful democracy, the nation had settled on a reliable means of casting and counting votes.

The scrutiny given to the vote in Florida opened our eyes to the very real possibility that, in the United States today, many votes are not counted. Many registered voters evidently went to the polls, cast ballots, and those ballots, for whatever reason, could not be counted. Still others made every attempt to vote but could not.

Journalists' investigations around the United States revealed that Florida was not the worst state and that Palm Beach was not the worst county. Illinois, South Carolina, and Georgia all had higher rates of spoiled or uncounted ballots in the 2000 presidential election. In Chicago, almost one out of every ten ballots for president did not register a vote. Chicago's problems were not limited to punch cards. From New York City came reports of improperly printed ballots and broken lever machines. From Beaver County, Pennsylvania, came reports of high numbers of unrecorded ballots using a new touchscreen computer voting system. From New Mexico came reports of voting disrupted by bad weather and power outages.

We are concerned about the potential long-term effects of such problems on Americans' confidence in their own electoral process. To many Americans this string of stories was just more bad news about the workings of American government, more reason not to vote, or more reason to turn away from public life. We cannot measure the strength of voters' confidence in the system. And, in fact, we think it would be foolhardy to wait for public opinion to sour before addressing the problems in the voting system. Once we lose confidence in a system as fundamental as voting, it is too late.

Today, many parts of the government are working to improve the voting system, with the aim of restoring voter confidence. In response to the controversy in Florida, many states and the federal government have initiated significant efforts to reform election administration. Local election administrators work continually to make their voting systems better. They are people personally dedicated to making democracy work.

Where to begin? How big are the problems with voting equipment in the United States? How do these problems compare to the other aspects of voting, such as registration? And what will it take to fix the components of the system and the system as a whole?

Lost Votes

We estimate that between four and six million presidential votes were lost in the 2000 election These are qualified voters who wanted to vote but could not or were not counted. Losses occur for two reasons: first, some voters do not, or cannot, participate due to problems with voter registration or polling place practices; second, some votes that are cast are not counted due to problems with ballots.

Two million ballots, two percent of the 100 million ballots cast for president in 2000, were not counted because they were unmarked, spoiled, or ambiguous. Of this two percent it is estimated that 0.5 percent did not intend to vote for president, so 1.5 percent (or 1.5 million people) thought they voted for president but their votes were not counted. Below the office of president the incidence of spoiled, unmarked, and uncounted ballots is much higher: five percent of ballots do not record a Senate or gubernatorial vote. And there are significant differences across equipment types in the incidence of uncounted ballots. For example, since 1988, three percent of voters using hand-counted paper and scanned paper ballots had no vote recorded for Senate or governor, but seven percent of voters using lever machines recorded no vote for Senate or governor. Thinking only about elections for Senate and governor, the differences across equipment add at least one million more votes to the numbers lost.

We lost between one-and-a-half and three million votes because of the registration process in 2000. According to the U.S. Census, Current Population Survey, 7.4 percent of the forty million registered voters who did not vote stated that they did not vote because of registration problems. Voter registration is an enormous database management system—a local census, if you like. Errors in databases occur even under the most scrupulous management. In practice, voters are not always careful in filling out registration information or in keeping their registration information current.

We lost between 500,000 and 1.2 million votes because of polling place operations. According to the U.S. Census, Current Population Survey, 2.8 percent of the forty million registered voters who did not vote in 2000 stated that they did not vote because of problems with polling place operations such as lines, hours, or locations. The figure was 1.2 percent in 1996.

We lost an unknown number of votes because of mishandled and controversial absentee and overseas military ballots.

4 TO 6 MILLION LOST VOTES

1.5 to 2 Million Lost Because of Faulty Equipment and Confusing Ballots
1.5 to 3 Million Lost Because of Registration Mix Ups
Up to 1 Million Lost Because of Polling Place Operations
Unknown Losses Because of Absentee Ballot Problems

The equipment figures come from our own analysis of lost votes. The registration and lines figures come from a survey conducted by the U.S. Census. We are more confident in the equipment figures. We take the survey figures at face value. They may be too high, owing to ambiguous wording in the Census question. We consider the survey data in the Appendix.

Miscounts and Misvotes

The recounts in Florida revealed another sort of error: mistaken votes and incorrect counts. The butterfly ballot confused many voters, producing mistaken votes. Thinking they voted for Candidate A, many people accidentally voted for Candidate B, because of the confusing layout of the ballot. Accounts of the recount noted that each time the punch cards were run through the counters, the tallies differed.

A systematic analysis of the rate of errors made by voters and by tabulation machines is needed to measure how large these problems are. This will require extensive testing and experimentation with equipment and ballots. That should be part of a larger, federal program on election administration.

In the area of tabulation, existing voluntary standards represent an important improvement. Existing standards developed in 1990 set minimum criteria for tabulation errors (on the order of one in 250,000 or fewer) of any new vote counting equipment. These standards are voluntary, and testing is performed on machine prepared ballots, rather than on ballots that are marked by people.

Security

Security of ballots and counts is a different sort of problem than lost votes or incorrect votes.

Fraud is, by its nature, hard to detect and measure. Stealing votes is a targeted attack on the electoral process, and those attempting fraud try to cover their tracks. This makes reliable measures of fraud tricky.

Fraud and security are social problems—people will commit fraud if they are willing to win by any means. Error is more of an engineering problem; we should make every effort to make machines, databases, and other aspects of the voting system more reliable. The social nature of security also means there are different solutions available. Penalties for electoral fraud and improved detection methods can act to deter individuals from conducting fraud. Judging by recent court cases, the greatest fraud problems may lie in absentee balloting (though registration also presents some problems), a part of the process that has less oversight than voting in precincts.

One cautionary note: some technologies are on their face suspect from the perspective of security. We are particularly concerned about the prospects of disruptions of voting over the Internet. A single attack targeted against Internet voting could have much bigger consequences than the diffuse sort of activities required to defraud precinct-based voting. We are also concerned about the secretive and proprietary treatment of tabulation software of all electronic voting. The fraud that occurs one ballot at a time or one lever pull at a time accumulates slowly like grains of sand on a scale. We are more concerned about someone putting his or her thumb on the scale.

PART II
WHAT IS

The Voting System

Voting is a system. It requires many steps: registering to vote, getting to the polls, casting a ballot, counting ballots, and certifying the vote. All the steps must come off without fail in order for a vote to count. All of the parts of the system must work well in order for the election result to reflect the will of the voters.

The challenge is to make voting less prone to error and more secure. In this section we consider the main components of the system. Subsequent sections detail the problems with specific elements of this system, beginning with equipment and registration, where we see the biggest problems lie.

An Overview

The voting system in the United States consists of four components: voter authentication, communication of voter preferences, the counting of these preferences, and security of the voting system.

First, there is a method for authenticating voters: voter registration. Weeks or months before Election Day, eligible voters who wish to vote must register with the county or municipality in which they live. The local government compiles a list of registered voters and distributes that list (or at least the relevant parts) to the polling places. When voters come to vote, poll workers verify that they are indeed eligible to vote at their polling place.

Second, there is a process for communicating preferences: balloting. To vote, people either go to public polling places on an appointed day and record their preferences on paper ballots or on voting machines, or people request an absentee ballot well before the appointed day. Americans vote using a wide range of different technologies, from paper ballots to touch-screen computers. Thousands of local governments and a few state governments make decisions about which voting technology to use and what the ballot will look like. A growing number of Americans (one in eight in the 2000 election) find Election Day inconvenient, and now vote “absentee” or “early.”

Third, there are procedures for counting ballots. For much of the nineteenth century Americans used paper ballots that were counted by hand; that system is still in use for about one percent of voters. Over the course of the twentieth century, voting equipment has evolved so as to speed up the count. These changes in technology have integrated the systems for casting ballots and counting ballots. Even with technology, however, many ballots are difficult to resolve. Because it can be difficult to determine a voter’s intention from the ballots and because machines fail, election laws in the states have evolved to clarify what counts and what does not.

Fourth, there is a security system. To prevent coercion and vote buying, the states have adopted secret ballots. Local governments provide for the security of the count through public counting of the votes and inspection and auditing of the tallies by local canvassing boards. Electronic counting procedures (punch cards, scanners, and electronic voting machines) make the count difficult to observe. The replacement for the openness that paper ballots provide is a system of standards for electronic tabulation, developed and implemented by individual states or by the Federal Election Commission and implemented on a voluntary basis.

The four components of the voting system are supported by an extensive, decentralized administrative operation. Elections are conducted by the states. Almost all states have given the authority for administering the elections to local governments. As a result, there are not fifty election divisions, but over three thousand election administrators maintaining voter registration systems, choosing equipment, formatting ballots, setting up polling places, handling absentee ballots, and conducting counts, audits, and recounts. The responsibility for paying for elections has also devolved to local governments. We estimate that all aspects of election administration cost counties roughly $1 billion in 2000.

How Did We Get Here?

Why does the U.S. voting system have this particular structure? Much of the voting system today—secret ballots, voter registration, machines instead of paper—evolved from reforms aimed at solving basic security problems: the corruption of voters. Today, people make somewhat different demands; in particular, we ask that it be more convenient.

Why can't I have a receipt to check that my vote was counted?

This question cuts to the heart of the problems of how to design easy-to-use and secure voting systems. A receipt is an easy check that every voter could use to make sure the process works correctly. However, receipts invite corruption. In the nineteenth century, we effectively did have receipts because ballots were not secret. The observable vote and, in some places, actual receipts allowed voters to trade their votes to local party officials and other political organizers for money, food, or alcohol.

Secrecy and anonymity of the ballot also provide important checks against coercion, against a person being forced, lured or intimidated into voting one way or another by others. In the late 1880s, almost all states adopted the secret ballot to combat widespread, organized vote buying. Receipts and other ways of violating secrecy raise the possibility of coercion.

Why don't people vote?

Only about half of all Americans who are eligible to vote in fact do. There are many reasons why eligible voters do not vote. Many of these reasons have little to do with voting technology or the voting system at all. Some people are simply not interested in politics. Many others say they are too busy or have difficulties getting to the polls. Even still, it is evident from studies conducted by the Census Bureau that many millions of **registered** voters who do not vote face obstacles to voting that could be lowered by correcting problems in the registration rolls or by making voting more convenient.

We make no promises about increasing participation. Our concern is with those who show up and wish to express their heartfelt preferences, but cannot. Voters should not be excluded because the equipment did not work or because of errors in the registration rolls.

Why do I have to register in order to vote?

Voter registration is used to manage who votes in elections. Voter registration systems have been in existence for most of the history of the United States. In the second half of the nineteenth century, voter registration systems became widely used to combat organized voter fraud in urban areas. Local political organizers coordinated "rovers": people who would go from precinct to precinct and vote.

Roving voters highlight two problems that registration aims to solve. First, registration systems are intended not only to ensure that voting is confined to eligible participants, but also to ensure that voters vote where they are supposed to. Representation in the U.S. is based on geography: voters are allowed to vote for only those offices that cover their home. Each polling place is provided with a list of registered voters eligible to vote at that polling place. Second, registration is used to make sure that everyone votes once. If a voter can register only once, then he or she can only vote where the voter is registered; the election officer can, then, keep track of who has already voted and who has not.

My bank finds me no matter what. Why can't voter registration be as well informed?

This is, in part, a consequence of decentralization. Every county and state today has its own voter registration system, and voter registration is distinct from other county databases, such as motor vehicle registrations, drivers' licenses, and taxation lists. So it is impossible for counties to keep track of voters.

Several states have begun ambitious efforts at unifying registration statewide. This will ultimately produce cleaner voter registration rolls, by connecting registration to other databases, such as motor vehicle registrations and vital statistics. Such integration is very expensive, but we believe that it will ultimately lead to a simpler registration and voter authentication system.

National voter identification cards are sometimes offered as an alternative to voter registration. Thanks to Napoleon, most European countries have citizen identification cards. These are used for voting, as well as many other government activities. The Anglo American countries—England, Canada, the U.S., and others—do not have such identification systems. Americans view national identity cards as undemocratic, giving the government too much ability to monitor us.

Why don't we have a uniform method of voting like other countries?

Because of our system of federalism, elections are overseen in the U.S. by the states. The states have given local governments (mostly counties) the responsibility for day-to-day management of elections, while state governments check that the election was run properly, certify the official vote, and handle some administrative tasks, such as, in some places, registration.

Congress could impose uniform technologies for casting and counting votes in national elections.

Many other federal nations, like Canada, have separate national and local elections and separate methods for casting and counting ballots. For example, Canada uses hand-counted paper in the national elections, but some cities use electronics for their local elections. The U.S. tends to have uniform methods for casting ballots in each county for all offices. This allows us to have fewer days on which elections are held and to vote for more offices on election days. It has meant giving greater authority for election administration to the locales, and thus more discretion about voting equipment.

Do we really need technology to vote? Why don't we just use paper and pencil like they do in Canada and France?

In the nineteenth century and well into the twentieth century most Americans did vote using hand-counted paper ballots. Most European countries still vote this way. Today only about one percent of Americans use hand-counted paper ballots. Are Americans just fixated with technology?

The scale of U.S. elections requires technological solutions. In a European national election, where only the legislative election is on the ballot, there is just one vote to count. In a U.S. election, paper is very hard to manage, from the administrator's perspective. Paper ballots are expensive to print, secure, and transport. Counting is slow, labor intensive, and cumbersome, especially in many U.S. jurisdictions where there can be twenty offices and twenty ballot questions. The history of voting technology in the U.S., from handcounted paper to optical scanning and touchscreen computers, is the history of producing a speedier, more reliable count.

Why can't I vote on the Internet?

Internet voting is here. The state of Arizona had one experiment with Internet voting in 2000, in the Democratic primary, and the Federal Voter Assistance Project ran a pilot project with the Defense Department for Internet absentee voting for overseas military personnel. We expect these experiments to grow, and the reason is simple: convenience.

Convenience voting is on the rise. Two decades ago only five percent of ballots were cast absentee or early; today that figure has grown to fourteen percent. The Internet is one of many technologies that can make voting more convenient.

However, Internet voting, in the judgment of many experts, is not ready for wide-scale use. There are three problems. First, there are concerns of coercion if Internet voting is done from remote locations, such as the voter's home computer. Second, large-scale fraud is more likely because it is easier to hack the entire system if it is on the Internet, than it is to coordinate many millions of voters voting at precincts or thousands of poll workers. Third, many people do not have computers at home or are sufficiently intimidated by computers that Internet voting (either from home or at the precinct) might create a further obstacle to voting for millions of voters.

Internet voting does hold immediate promise for lowering the obstacles experienced by some voters. Technology today presents very significant obstacles to special classes of voters—most notably blind people (who cannot use visual systems and who have difficulty with transportation) and overseas military personnel (who cannot get to the polls and for whom traditional registration and absentee procedures are very difficult).

The controversy over Internet voting and the answers to these other questions carry an important lesson. The way we vote is not static, and the decisions we make today will shape the future.

The voting system we have today evolved in response to specific problems. The most significant problems that have shaped our system were those of corruption and fraud, especially organized attempts to buy or steal votes. Fraud led to registration, secret ballots, and technologies for tabulation. Security considerations are fundamental to any changes made today in the voting system.

Today, there are additional problems, highlighted during the election controversy in the 2000 presidential election. We should have voting equipment that minimizes errors made by voters in casting ballots and that minimizes errors by machines in recording and counting ballots. We need a highly accurate and secure system for authenticating voters; currently, that is the voter registration system. We should have a very secure system for "convenience voting," so as to guard against fraud in absentee ballots and to ensure that people who cannot be at the precincts can vote with confidence. We should have a highly secure system for electronic transmission and tabulation of votes. We need a less ambiguous process for conducting recounts. And the U.S. has the opportunity now to lay the foundation for the future of voting.

Before we turn to what that future could be, we address the specific problems today, beginning with election equipment.

Equipment

Voting equipment was central to the election controversy in Florida in 2000. The recounts revealed many tangible problems voters had with ballots and machines and the resulting ambiguities in the tallies. Butterfly ballots and dangling chads instantly became part of the national lexicon.

But Florida was not unique. Florida had a relatively high rate of unmarked, uncounted, and spoiled ballots for president—three percent of all votes. Several other states, including Georgia, Idaho, Illinois, South Carolina, and Wyoming, had higher rates of unmarked, uncounted, and spoiled ballots. Some cities, including Chicago and New York, had rates of unmarked, uncounted, and spoiled ballots well in excess of the state of Florida.

The equipment used to cast and count ballots loses millions of votes nationwide each election. Over the past four presidential elections, two out of every one hundred ballots cast registered no presidential vote. That rate is double in Senate and gubernatorial elections. Analysis of exit polls suggests that seventy percent of these uncounted votes are unintentional. In other words, approximately 1.5 million votes for president were "cast" but not recorded or counted in 2000. Approximately 2.5 million votes for Senate and governor were "cast" but not recorded or counted over the last cycle.

The U.S. can cut the number of lost votes due to voting equipment in half by 2004 using equipment that is already available. We should replace types of equipment that show high rates of uncounted, unmarked, and spoiled ballots with optically scanned paper ballots that are scanned at the polling place by the voter (called "in-precinct optical scanning"). As we document below, such in-precinct optical scanning has, on average, half the rate of uncounted ballots as punch cards and lever machines. In-precinct optically scanned ballots are not the only technology available today, but use of that technology could cut the rate of uncounted, unmarked, and spoiled ballots immediately.

RECOMMENDATION

Replace types of equipment that show high rates of uncounted, unmarked, and spoiled ballots with optically scanned paper ballots that are scanned at the polling place by the voter (called "in-precinct optical scanning"), or any electronic technology proven in field tests.

In-precinct optical scanning is not ideal. It still loses votes. But it would represent a considerable improvement.

But we should also not lose sight of the future. Voting technology is evolving quickly. Many new machines are in development; they are untested but hold great

A Provocative Scenario: It is 2002, and in a close U.S. Senate election, punch card ballots once again do not record a large number of votes unambiguously. The Secretary of State certifies a winner who holds a lead of 500 votes, among one million cast. The outcome of the race is in doubt. A recount is conducted, and a court battle over the count ensues.

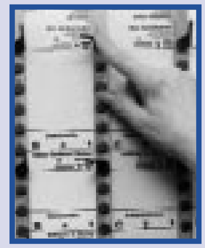
Electronic Voting

Punch Card

Optical Scan

Paper Ballot

Lever Machine



promise. The best we can do today with upgrades is to reduce the average rate of lost votes in presidential races to about one percent of total ballots cast. We fully expect that new technology—technology that is currently in development—can reduce lost votes further and can break through other barriers in voting, such as handicapped accessibility.

What Equipment Do We Use Today?

Americans vote with five different technologies. These technologies differ according to the way votes are cast and counted.

Three technologies are based on paper ballots—hand-counted paper ballots, punch cards, and optically scanned paper ballots. Hand-counted paper ballots are the oldest technology currently used in national elections. Nearly universal in the U.S. in the nineteenth century, they remain widely used today in rural areas. Punch cards and scanners improve on hand-counted paper ballots by automating the count. Punch cards, which were introduced in the 1960s, require the voter to indicate his or her choice by making holes in a heavy stock card. Optically scanned paper ballots, which experienced explosive growth in the 1990s, require the voter to indicate his or her choice by filling in a circle or completing an arrow, much like answers to standardized tests are recorded.

These paper-based technologies differ in how they are counted. Election officials make tallies of hand-counted paper ballots. Scanning devices perform the tallies for the other two technologies. Card readers record the preferences of voters based on which holes appear in the punch card. Infrared optical scanners read the marks made on the scannable paper ballots.

Two other voting technologies involve machines that directly record the vote—mechanical lever machines and electronic voting machines (called Direct Recording Electronic machines, or DREs). With a machine, the voter records his or her preferences on an "interface." For the older lever machines, which were first introduced in the late nineteenth century, the interface is a set of levers associated with each candidate or answer to a ballot question. For the newer DREs the interface is a set of physical buttons or regions on a touchscreen that records a voter's choices.

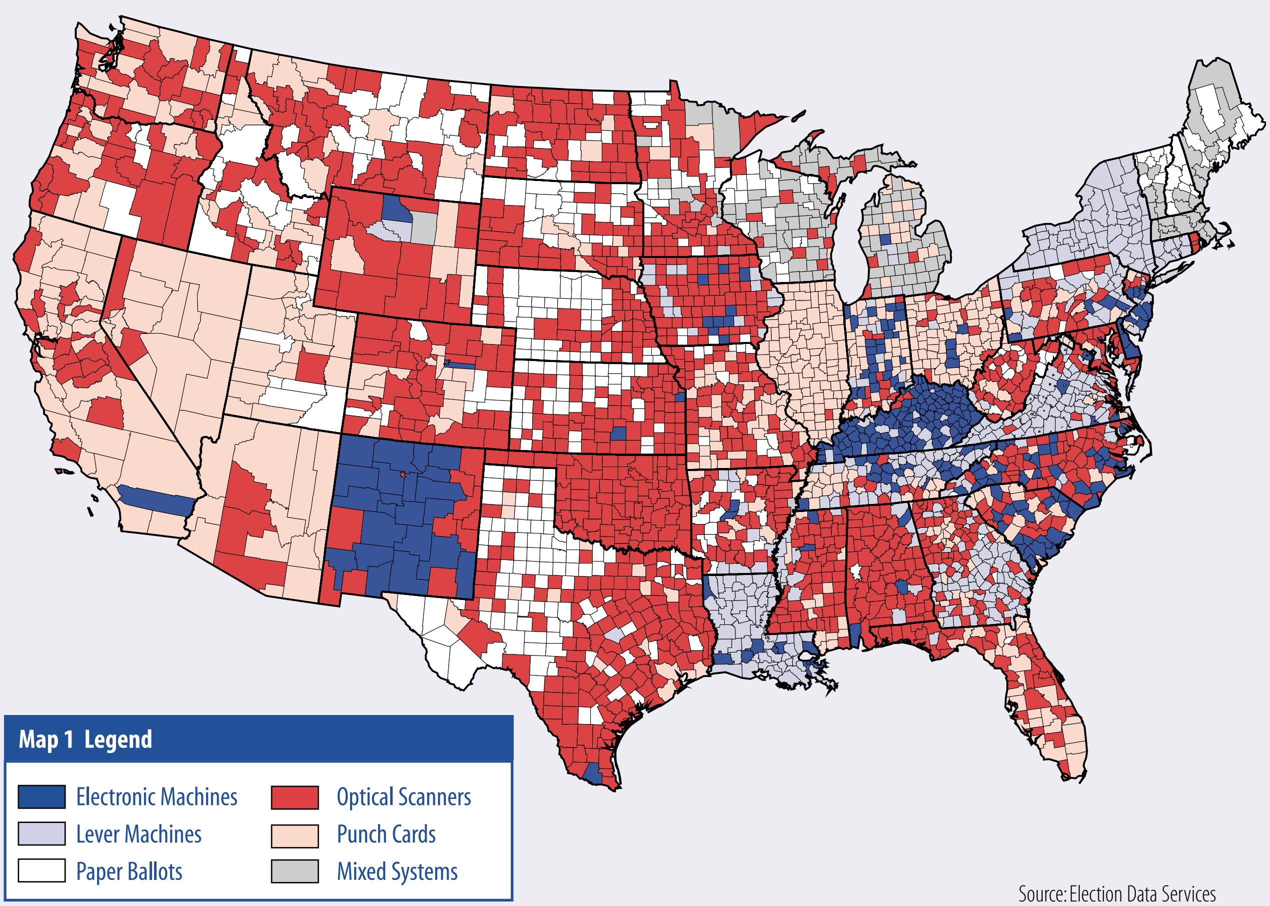
Whether the machine is mechanical or electronic, it unifies the casting, recording, and counting of votes in one apparatus. This has the advantage of eliminating the mass of paper that must be managed with paper-based systems. Vendors often play up this particular feature of these systems, as managing paper is a big administrative headache for local election officials.

There are also important costs to the unification of equipment. Lever machines and DREs do not provide a separate record of the voter's intent apart from that captured by the machines. Election officials can only recount what the machines record, so it is impossible to conduct a thorough audit of the election. And, probably most importantly, the user-interfaces are less familiar to voters than paper. This makes it especially challenging to design interfaces that do not confuse or intimidate voters. Because these machines are sold with their interface in place, only marginal improvements in the interface design can be made once the machines are acquired by local governments.

There are several important variations in the implementation of the designs of each of these five voting technologies. For instance, optical scanning is performed two ways—at the polling place ("in-precinct count") and at the local election office ("central count"). In-precinct counts are widely thought to be superior because they give voters a chance to change their ballots to fix any mistakes detected by the scanner at the polling place.

Perhaps the biggest variations in design and implementation, though, are among the electronic machines. Older varieties of DREs are modeled explicitly on lever machines—they are essentially electronic lever machines. They present all choices at once ("full face") on a large panel with push buttons. Such machines currently dominate the market, comprising

Voting Equipment Used by Counties in 1999



Source: Election Data Services

approximately two-thirds of all counties using electronics. Newer technology relies on touchscreens and keypads much like automatic teller machines at banks. This technology is still infrequently used. It does have the potential to allow for upgraded and more flexible user interfaces (e.g., many languages).

Map 1 on page 19 shows the great diversity of equipment used in the United States in 1999. Counties using hand-counted paper—the oldest system—are in white. This technology is used almost exclusively in rural areas today. Shades of red show counties that use the other paper systems—pink for punch cards and red for scanners. Shades of blue show counties that use machines—light blue for levers and dark blue for DREs. In some states, municipalities choose equipment and there is variation within the county. These states are shown in gray in the map. These data were collected by Election Data Services and by our project.

In the most recent election, only one in one hundred voters used hand-counted paper. One in three voters used punch cards. Slightly more than one in four voters used scanners. One in six voters used lever machines. And one in ten voters used electronic voting equipment. This pattern represents a significant change since 1980, when sixty percent of all votes were cast using lever machines or hand counted paper.

Over the past twenty years, local governments have increasingly abandoned traditional paper ballots and mechanical lever machines, in favor of methods that employ electronics in one way or the other, either to record the vote or count the vote or both. The Florida experience in 2000 has stimulated a number of states, including Florida itself, to abandon the first generation of computer-assisted voting, punch cards. There are, then, two types of technologies to choose between in the immediate future: optical scanning and electronics. How do they compare from the perspective of lost votes?

How Much Does Voting Equipment Contribute to Lost Votes?

Residual Votes and Lost Votes

Residual votes—the number of uncounted, unmarked, and spoiled ballots—provide a yardstick for measuring the effect of different machine types on the incidence of lost votes.

RESIDUAL VOTES =

Uncounted ballots + Unmarked ballots + "Overvoted ballots"

BALLOTS THAT CONTRIBUTE TO THE RESIDUAL VOTES

Uncounted ballots: Ballots that are cast by voters but uncounted by election officials for whatever reason.

Unmarked ballots: Sometimes termed the "undervote." May occur because the voter abstained or the recording device did not register a mark.

Overvoted ballots: Ballots that record a vote in more than one place for a given office (unless the ballot explicitly allows for more than one choice to be made.) May occur because the voter clearly marked more names than allowed. Often occurs when a voter places a legal mark next to a candidate's name and then writes the same name on the "Write-in candidate" line on the ballot.

Over the past four presidential elections, the rate of residual votes in presidential elections was slightly over two percent. This means that in a typical presidential election over two million voters did not have a presidential vote recorded for their ballots. The presidential race is the "top of the ticket." The rate of residual votes is even higher down the ballot—five percent for Senate and gubernatorial elections. In other words, almost five million votes are not recorded for other prominent statewide offices.

A ballot may show no vote because the machine failed to record the voter's preferences, because the voter made a mistake or was confused, or because the voter did not wish to vote for that office. The first two reasons would mean lost votes. The third would not be a lost vote, but would be a correct recording of the voter's preferences. It is difficult to judge intentions, but exit polls suggest approximately thirty percent of residual votes are intentional. This implies that 1.5 million presidential votes are lost each election; 3.5 million votes for governor and senator are lost each cycle.

A more conservative measure of the number of votes lost due to equipment is the number of ballots for which voters chose more than one candidate—an overvote. We focus on residual votes because the distinction of overvotes from other kinds of errors is a false one.

Technology can enable or interfere with voting in many ways. Lost votes are not just a matter of preventing someone from accidentally voting twice. Vote loss can happen because of machine failures. Vote loss also happens because ballot designs or user interfaces confuse voters or even obscure how to vote. Ballot and user interface design is perhaps the most important cause of vote loss, and different types of technology rely on specific types of ballots and user interfaces.

Table 1

RESIDUAL VOTES AS A PERCENT OF ALL BALLOTS CAST, 1988-2000

Machine Type	President	Governor & Senator
Paper Ballot	1.8%	3.3%
Punch Card	2.5	4.7
Optical Scan	1.5	3.5
Lever Machine	1.5	7.6
Electronic (DRE)	2.3	5.9

Whatever the cause, the residual vote rate should not depend on what equipment is used. But it does.

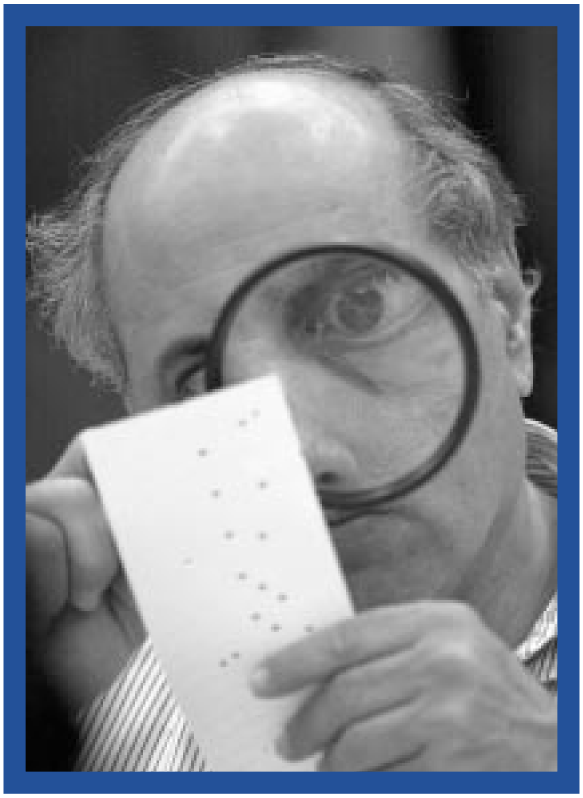
The Relationship between Voting Equipment and Residual Votes

A simple table reveals the extent to which equipment affects the number of votes lost. Table 1 presents the residual votes in presidential elections and in Senate and gubernatorial elections as a percent of all ballots cast over the past decade.

The figures in Table 1 reveal a striking pattern. Some technologies consistently perform well on average, and some technologies have excessively high rates of residual votes. In particular, paper ballot systems tend to show lower residual votes than lever machines and electronic machines. To the extent that there is an exception to this pattern it arises with punch cards.

Optically scanned paper and hand-counted paper ballots have consistently shown the best average performance. Scanners have the lowest rate of uncounted, unmarked, and spoiled ballots in presidential races and in Senate and gubernatorial races. Counties using optical scanning have averaged a residual vote rate of 1.5 percent in presidential elections and 3.5 percent in Senate and gubernatorial elections over the past twelve years. Hand-counted paper has shown similarly low residual vote rates.

Punch cards, the other paper based system, lose at least 50 percent more votes than optically scanned paper ballots. Punch cards have averaged a residual vote rate of 2.5 percent in presidential elections and 4.7 percent down the ballot. Over thirty million voters used punch cards in the 2000 election. Had those voters used optical scanning there would have been 300,000 more votes recorded in the 2000 presidential election nationwide and 420,000 more votes in Senate and gubernatorial elections. Counties using paper ballot systems should choose either traditional hand counting or optical scanning in order to lower the number of lost votes.



Machine voting, on the whole, has performed significantly worse than the paper systems. Lever machines lost relatively few votes in the past four presidential elections, averaging a residual vote rate of 1.5 percent. Electronic machines lost nearly as much as punch cards, averaging 2.3 percent over the past four elections. The more severe problems appear down the ballot with these technologies, and here we see real concern with the continued use of lever machines. In recent Senate and gubernatorial elections, the average residual vote rates of lever machines and electronic machines were 7.6 percent and 5.9 percent, respectively, of all ballots cast. Had the counties using lever machines used optical scanning, we estimate that there would have been 830,000 more votes recorded in Senate and gubernatorial elections.

These patterns hold up to closer statistical scrutiny, holding constant turnout, income, racial composition of counties, age distributions of counties, literacy rates, the year of a shift in technology, the number of offices and candidates on the ballot, and other factors that operate in a county or in a particular year. For a fuller discussion see our report "Residual Votes Attributable to Technology: An Assessment of the Reliability of Existing Voting Equipment," available at www.vote.caltech.edu.

The immediate implication of our analysis is that the U.S. can lower the number of lost votes in 2004 by replacing punch cards and lever machines with optical scanning. Punch cards and levers are, in our assessment, dominated technologies. That is, there are voting technologies available today that are superior, from the perspective of lost votes. Scanners consistently perform better than punch cards and levers. We also believe that optical scanning dominates older full-faced, push button DREs, which comprise fully two-thirds of the electronic machines in our analysis. Touchscreens are, in our opinion, still unproven. Some counties, like Riverside, California, have had good experiences; other counties like Beaver County, Pennsylvania, and many counties in New Mexico had very high residual vote rates (over five percent in 2000).

This is not to say that optical scanning is an ideal system. It has plenty of faults and problems. This system also loses a significant number of ballots, though less on average than other systems. Election officials complain of paper jams, the cost of printing, and ballot management. Scanning is imperfect, but it is the best of what is.

For counties thinking of adopting optical scanning, there is a further question. Which sort of optical scan system is best? There are at least two different scannable ballots forms—connect the line and "bubble ballots." Also, scanned ballots can be counted centrally (at the county election office) or they can be checked and counted at the precinct. There is some evidence from the 2000 election, from states like Florida and Michigan, that precinct scanning has lower residual vote rates. Precinct scanning allows voters to fix their mistakes. The strengths and weaknesses of these specific aspects of scanning need to be more carefully and fully investigated before recommendations can be made.

We were most surprised by the comparatively poor performance of electronic voting machines. After all, we represent Institutes of *Technology*. One interpretation of our findings is that electronic voting is inherently flawed and should not be used. We disagree.

Electronic voting equipment has many apparent advantages. Unlike paper or punch cards it can be prohibited from registering overvotes. Unlike paper or cards, miscounting is virtually impossible. It is also possible to design interfaces for blind voters and to provide customized ballots on the spot.

We believe that the high rate of residual votes of DREs stems from the user interfaces. We have examined many of these machines. The mechanics of voting on these machines are often confusing. It is often not obvious how to undo a selection, how to check that all races have been voted, how to distinguish between the offices, and how to register the votes. Some interfaces are "too responsive": a voter can push a button for the next page and more than one page will pass by without the voter seeing it. The formatting of the "ballot"—the presentation of choices—is often confusing as well. It is sometimes unclear where one office (a set of candidates to choose among) ends and the next one begins. Ballot design is a problem with all equipment and lever machines, in particular.

We have also encountered physical reliability problems with some commonly used DREs, including lose connector cables that zero out the counters and blown fuses. Connector, cable, programming, and set-up problems can interfere with the conduct of elections. While the technology used is often excellent, the implementations have not always been at the level of other professional computer systems.

We see electronic voting as an improving technology. It has great potential. However, in terms of one very basic requirement—minimizing the number of lost votes—electronic voting does not have a very good track record. Paper systems have performed much better over the past dozen years. This problem means that the electronic voting industry is not working to the standards that it needs to. Our report holds this as a priority. It is unquestionably possible to make high quality, simple interfaces and manage complexity with computer technologies that exist today.

How Can Local Governments Acquire New, Expensive Equipment?

Election administrators must weigh not only the performance of equipment, but the cost of acquiring and operating their machines. The two viable technologies in the near term for most counties are optical scanning and electronic voting. What are the acquisition and operating costs associated with optical scanning and electronic voting?

ESTIMATED COSTS OF BUYING AND OPERATING VOTING EQUIPMENT

	Acquisition	Operating
DRE Machines (Touchscreen)	$18-25/voter	$0.5-1/voter
Optical Scanning (in Precinct)	$6-8/voter	$1-2/voter

Election Systems and Software, Inc. (ES&S), and Guardian Voting Systems, a division of Danaher Controls, two of the largest voting equipment vendors, provided us with information on acquisition prices and operating costs for different kinds of equipment. Their figures square with each other and with recent equipment purchases.

Assume that the life of these machines is fifteen years. The total cost of the equipment is the acquisition cost plus fifteen times the operating cost. The total cost of a touchscreen DRE system comes to approximately $32.75 per voter over the entire fifteen year span. (We use $21.50 for the acquisition cost.) The total cost of an optical scanning system comes to $29.50. (We use $7.00/voter for the acquisition cost.) Even though optical scanning systems have much higher operating cost, the difference in the acquisition cost is sufficiently large that the total cost of the optical scanning system is somewhat lower over the fifteen-year operating life of the machinery. If we assume a twenty year lifespan, the costs are identical.

For an election administrator these numbers seem daunting. A city with 250,000 registered voters would spend $5 million to purchase equipment. This sum exceeds the total election administration budget of a city this size. Leasing is one possible solution, as we discuss later in "Cost and Public Finance of Elections."

Other Considerations

Reducing the number of lost votes is a very important goal, but it is not the only factor in choice of equipment. Security and misvotes are also important, though we know of no data on these factors. Three further considerations are auditability, management, and accessibility.

Auditability

In the 2000 presidential election, the state of Florida conducted an enormous audit of its voting machines. It checked the record of the vote cast—the punch cards and scanned ballots—against the final tally.

It is extremely important to be able to conduct such an audit. So long as we can verify the official count through a systematic recount of the votes we can avoid having to call an entirely new election, a revote.

Paper ballots have the highest degree of auditability. The voter records on paper what he or she intended. This can always be examined in a recount, if it has not been lost or stolen.

Lever machines and older direct recording electronic machines offer no auditability. If a machine is jammed or broken, the recorded tally will not reflect the votes that people cast. The votes cast on a broken machine can never be reclaimed. For this reason alone we feel that lever machines and older DREs should not be used.

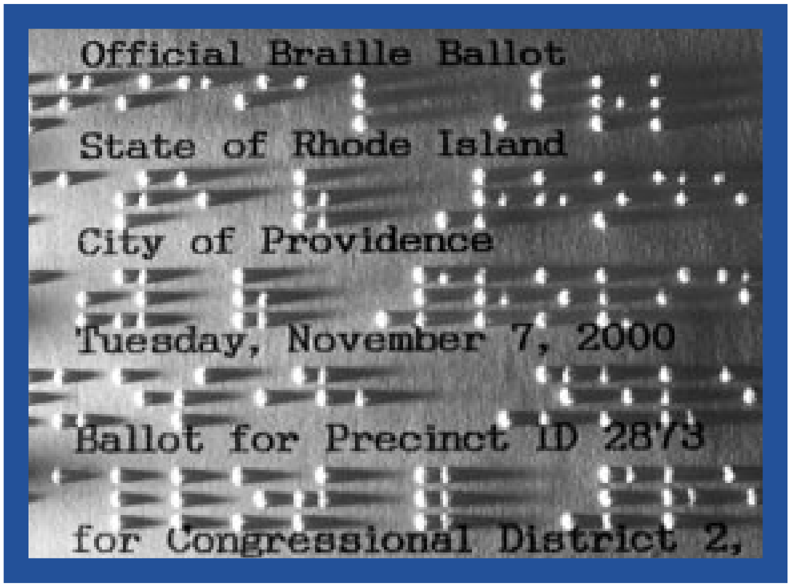
Most new electronic machines produce an internal paper tape (like a cashiers tape) and an electronic recording of every voting session. This allows officials to reconstruct what was done on the machine. While this is an improvement over other machines, it is not a direct recording of the voter's intention. If the machine fails between the touchscreen and the tape, the voter's stated intentions are still lost.

We feel that new voting standards must require a minimum level of auditability. The industry is searching for such a standard on its own, mainly through demand from local election administrators. This is a situation, though, where clear standards should be set nationally; the equipment industry can build to those standards.

Management

Managing ballots and equipment on Election Day is a Herculean task. Little things can happen that are difficult to control but that produce lost votes. One of the more alarming stories in Florida involved a poll worker who accidentally took home a bag of ballots, thinking the bag was his laundry. There was no malicious intent, but the example shows how insecure the ballots really are and how difficult it is to keep track of all ballots on Election Day.

Different technologies pose different management challenges. Machines, especially lever machines, are costly to store, maintain, and deploy. Paper ballots—hand counted, scanned, or punched—must be transported and processed, an especially difficult task if ballots are counted centrally. Los Angeles County, California processes 2.8 million ballots in one night. County election officials must coordinate the transportation and counting of all those ballots.



Accessibility

One of the most challenging problems facing voting today is making voting accessible to all eligible voters. Today there are two obvious and difficult obstacles: disabilities and language. People with disabilities often cannot vote without assistance. There are two million blind people in the United States, none of whom can vote without assistance. People who do not speak English with comfort or who are illiterate often cannot vote without assistance.

The voting equipment industry has been grappling with these problems in recent years. It has made some progress developing machines that are usable by blind voters. Many new DREs offer recorded instructions on how to vote. The voter must still navigate the touchscreen or push button. This represents a very important advance, but we know of no studies of the performance of these machines. We strongly recommend human testing of equipment for errors in voting and ease-of-use of equipment accessible to blind voters.

New interface designs and machine architectures may be needed to solve accessibility for blind voters and for voters who need assistance reading English. We think the best approach to addressing these problems involves federal investment in research and development of appropriate designs and equipment.

Registration

Along with the secret ballot, voter registration provides a basic check on the integrity of voting in the U.S. Registration does two things. First, registration information is used to control who votes. Only those who are eligible to vote can register. Poll workers use the registration rolls to authenticate voters at the polling places. This is a check on roving voters, non-citizen voting, and other abuses. Second, registration information is used to manage ballots. The addresses on the registration lists determine where people are eligible to vote and, therefore, which ballot a voter is supposed to receive.

Voter registration is essentially a state census, administered locally, and developed exclusively to manage voting. Performing this census is a daunting task. Start with the numbers. The number of potentially eligible voters in the United States—the "voting age population" (VAP)—is over 200 million. The voting age population grows about two percent nationwide every two years. In the four years between presidential elections, local election officials have to deal potentially with four million new voters simply due to the natural increase in the population.

RECOMMENDATION

Near Term

- Develop a system for allowing voters to check their registrations.
- Develop better databases (e.g., record some sort of numerical identification on each voter's registration).
- Make the county's or state's registration database accessible at each polling place.
- Provide polling places with the list of dropped voters and the reason they were dropped.
- Use "provisional ballots" aggressively when there are registration problems.

Long Term

- Computerize voter registration information and processes at both the local and state levels.
- Develop statewide qualified voter files.
- Fix gaps in the more open registration system created by NVRA.

National legislative changes in the 1990s added significantly to the burden local election officials face in registering new voters who come of age, removing those who die, and handling changes of address. Most significant was the National Voter Registration Act of 1993 (NVRA), or "Motor Voter," which imposed many new requirements on local officials, in an effort to make registration itself more convenient and to make it more difficult to purge inactive voters from the rolls.

The added convenience of registration has encouraged the number of registrations to grow, to the point where the number of new registrants is vastly outstripping the natural increase in the number of eligible voters. For instance, between 1994 and 1998, the size of the eligible voting population grew by 4.3 percent (8.3 million people); over that same time the number of registrants grew by 19.6 percent (25.7 million people).

However, this big increase in registrants has not produced a concomitant increase in the number of voters. Consequentially, one immediate effect of the NRVA has been to increase the number of "inactive" registrants, from 1.7 million in 1994 to 14.6 million in 1998.

Registration is a significant, never-ending task. With the promise of expanded voter participation, the NVRA also brought new administrative headaches that are only now beginning to be adequately addressed by states and localities.

To manage this task, a voter registration system must meet five standards.

First, registration information must be accurate and complete. The information on the voter registration rolls must cover all registered voters and have the correct information used to authenticate the voters, that is, to verify that the voter is eligible to vote for a prescribed set of races.

Second, registration information must be immune from fraud. If the aim is to prevent fraud, then it should be difficult or impossible to create fraudulent registrations.

Third, registration information must be dynamic and up-to-date. Voter registration must be flexible to accommodate frequent moves made by previous voters, the addition of new voters, and late voter registrations. Registration must also fit with election schedules. A significant challenge is developing a fraud-resistant system for last-minute registrations, including Election Day registration.

Fourth, registration information must be usable by the election officials at the polling places. Because election officials use this information to authenticate voters, polling place workers must have usable registration information.

Fifth, it must be easy for voters to register. Registration should not be a burden to voters.

When we began this project, election administrators told us that their biggest problems lie in the area of registration. Problems maintaining the registration system make it very difficult to control who votes and to manage ballots on Election Day. These are very big problems.

A Provocative Scenario: It is 2002, and in a close U.S. House election, 5,000 potential voters, out of 100,000 cast, claim they were turned away from the polls on Election Day. Almost all of these were people who registered to vote when they renewed their driver's license. Further investigation reveals that the local election supervisors had not processed a backlog of registration forms that had arrived well before Election Day. Enough qualified voters were turned away that the courts declare the initial election result invalid. A revote is ordered. The declared winner of the original election challenges the revote. The House of Representatives, in which the majority party holds a two-seat advantage, must decide whether to seat the original winner, go along with the court-ordered revote, or follow some other course to settle the election dispute.

First, errors in the registration rolls prevent some people from voting. Registration is a large database management problem. As in any database, errors can occur many ways. Voter registration databases suffer from typographical errors, dropped registrants, and outdated information. Nationwide, the Census Bureau estimates that in the 2000 election three million *registered* voters did not vote because of problems with their registrations.

Second, fraudulent or outdated registration may allow fraudulent voting. People who are not eligible to vote may try to register. Examples of such fraudulent registrations include registration by non-citizens or registering multiple times. People may use other people's registration information to vote. The most notorious examples involve recorded votes by dead people. It is unknown how much fraudulent voting

occurs because of registration failures. One study, sponsored by the *Atlanta Journal and Constitution*, discovered that fifteen thousand dead people were on Georgia's voter rolls, out of a total of 3.6 million registered voters. Over a twenty-year period, 5,400 dead people were discovered to have voted in Georgia.

Audits of voter registration systems have found astounding numbers of duplicate registrations. Los Angeles County, California recently audited its registration rolls and found that one in four registrations were duplicates (usually because people moved). When Michigan updated its voter files, the state discovered one million duplicate registrations (out of nine million registered voters). There is little evidence that such duplicate registrations have led to widespread duplicate voting.

Improvements in the accuracy of registration systems are needed in order to prevent denial of access to the polls, to prevent significant fraud, and to assure legitimate voters that their votes are not diluted.

Why Do These Problems Exist?

Perhaps the most important explanation is that registration is a massive, complex database. In any system large enough to keep track of 150 million registered voters there will be typographical and other data errors. Changes in the population complicate matters. Americans move a lot. In March 2000 the Census Bureau estimated that over fifteen percent of eligible voters had moved *in the previous year*. So the rolls are in constant flux.

A second factor contributing to the problems with voter registration is that it is decentralized. Management of the voter registration system is handled in most states by local governments that do a good job with limited resources. Duplicate registrations and other problems, however, emerge because there is no method for coordinating these local governments' registration databases. If a voter moves, there is no ready method in most states for updating that voter's registration, apart from the voter taking the initiative to change registration in both counties. This is a hassle. Even within a county, people move without updating their registration. Some of these people try to vote at their new addresses but cannot.

A third factor is that voter registration information is difficult to deploy on Election Day because of the precinct voting system. There are well over three thousand jurisdictions that manage voter registrations, but there are approximately 200,000 polling places, each of which needs access to the registration information. Almost all counties distribute registration information to the polling places by printing out the list of people who are registered and eligible to vote at a specific polling place. Handling problems at the polling places is very time consuming: the poll worker typically must call the central election office to verify registration information whenever there is a problem. This distracts from other activities at the polling place, including attending to voters who need assistance.

Addressing these problems is a continuing activity of localities, and increasingly the state and federal governments. The most significant recent federal legislation is the NVRA. This law set standard procedures for purging registration rolls and allowed voters to apply to register at departments of motor vehicles and other public offices.

The NVRA lowered many barriers to registration and addressed many civil rights problems. But, it may have exacerbated database management problems. Many registration applications do not make it to the local election office. As a result some people think they are registered where they are not.

The U.S. must continue its efforts to improve registration. We have the following concrete recommendations toward this end.

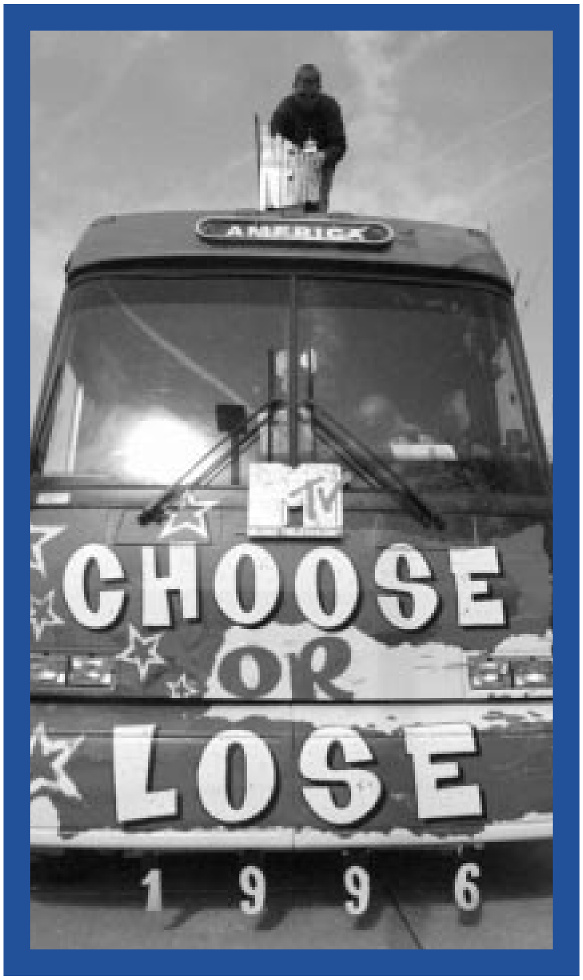
First, develop a system for allowing voters to check their registrations. This might be done by publishing all registrations in a local newspaper at least a week in advance of the closing of registration or by sending post cards to all registered voters or to all residences with the current information. Some counties in North Carolina now allow voters to verify whether they are registered to vote via the Internet.

Second, develop better databases. A simple step is to record some sort of numerical identification on each voter's registration. We recommend driver's license numbers or the last four digits of the Social Security number. Only fourteen states require information that could be used as a database index, though over half request such information. Such an index is essential for managing purges and duplicates. With such an index the state could verify whether registrations with common names (like Joe Smith) are duplicates.

Third, make the county's or state's registration database accessible at each polling place. We recommend putting the complete registration database for a county on a compact disk and leasing a laptop computer for each polling place. Where this has been done it has reportedly eliminated a majority of registration problems and reduced polling place bottlenecks.

Fourth, provide polling places with the list of dropped voters and the reason they were dropped. Many registration problems arise because of incorrectly purged rolls. Even without providing the countywide information, these problems could be fixed by providing the list of purged voters.

Finally, counties should use "provisional ballots" aggressively when there are registration problems. A provisional ballot is a "fail safe" method that can be



First, the counties and states should computerize voter registration information and processes at both the local and state levels. Many states, like Michigan and Oklahoma, have already begun such a process. It is essential for guaranteeing the integrity of the voter registration rolls. It is a very expensive process. Federal funding could help in this process.

Second, develop statewide qualified voter files. Several states have begun to develop such files. This would allow for thorough checking of duplicates, and may make it easier to detect fraud.

used when a potential voter's registration status is challenged at the precinct. A voter who votes a provisional ballot is allowed to make choices among offices that are common to all voters in a county, including all statewide and county offices, and possibly state legislative offices, too. The ballot is then sealed in an envelope, along with an affidavit from the voter declaring that he or she is eligible to vote. After Election Day, the registration status of the voter is verified. Individuals who should have been allowed to vote then have their ballot counted. Individuals whose registration does not check out have their ballots discarded.

We estimate that aggressive use of provisional ballots could itself cut the rate of lost votes associated with registration problems in half. Currently two-thirds of the states do not use provisional ballots, and many locales that provide for them do not use them aggressively. In Los Angeles County, California, two-thirds of the provisional ballots that were issued on Election Day in 2000 were valid ballots. These two facts suggest that aggressive use of provisional ballots could cut lost votes due to registration problems by half nationwide. That is roughly 1.5 million lost votes.

We must also consider long-term changes in the registration system. Stop-gap and fallback measures, like provisional ballots can alleviate problems, but they represent superficial corrections for deeper problems.

BEST PRACTICES IN MANAGING VOTER REGISTRATION

The Michigan Qualified Voter File (QVF)

The QVF provides electronic linkage for elections officials throughout the State of Michigan to an automated and integrated statewide voter registration database (http://www.sos.state.mi.us/election/qvf/index.html).

California "On-line" Voter Registration

California's "on-line" voter registration process allows for easy distribution of voter registration forms via the Internet (http://sosdev3.ss.ca.gov/votereg/OnlineVoterReg). The system does not allow for truly "on-line" voter registration, as a paper-based signature is still required.

Orange County, Florida

County workers with laptop computers containing countrywide voter registration information assisted with voter authentication in the polling places, reducing registration problems at the polling places significantly.

Federal Voting Assistance Program (FVAP), 2000 Voting Over the Internet Pilot Program

The FVAP's 2000 Voting Over the Internet program developed an on-line voter registration process that involved a high degree of computer security.

Third, we must fix gaps in the more open registration system created by NVRA. Some states and locales have integrated their voter registration databases with other county and statewide databases, especially those agencies relevant under the NVRA. We are concerned about the procedures for third-party registrations. Some organizations that solicit new voter registrations never forward the registration forms to election registrars. Some organizations may even use the prospect of registration as a way of collecting information about people. One might allow only official government offices to conduct on-line voter registration.

Fourth, develop electronic authentication of voter registration at polling places. We estimate that leasing a laptop for Election Day costs $100, and the wages of a county employee in charge of the laptop would cost $400. With two elections per year the cost comes to roughly $2 per voter per year.

States and counties have already initiated reforms along these lines. Several examples of reforms and best practices deserve to be highlighted, especially as other states and locales can learn from these experiences. Included among these are the Michigan Qualified Voter File, the California "on-line" voter registration process, a program in Orange County, Florida to use laptop computers to deal with registration issues in the precincts, and the Federal Voting Assistant Program's 2000 "Voting Over the Internet" pilot program.

Polling Places

Polling place lines are part and parcel of every Election Day news account, and 2000 was no different. A legal tug-of-war happened in St. Louis in the 2000 election, and it may have affected the outcome of the U.S. Senate election in Missouri. What we find especially troubling about polling place lines and closings is that voters who have done everything right are denied access to the vote. Voters who register, study the choices, make the effort to go to the polls, and arrive on time can be denied the vote because of unusually long lines at the very end of the day.

According to the U.S. Census, in 2000, 2.8 percent of registered voters who did not vote said that they did not vote because the line was too long or the hours were too short. That is approximately one million voters.

RECOMMENDATION

Election Administrators should measure the performance of individual polling places in the areas of arrival process, authorization to vote, voter education, and staffing practices and adopt management principles to improve service.

Polling place set up is a logistical challenge. The typical polling place handles 400 to 500 voters on Election Day. There are approximately 200,000 polling places in the U.S. on Election Day, staffed by 700,000 employees hired just for the day. The pay is minimal.

The polling place is a service system; it provides the service of voting. The voter is the customer with certain requirements. Namely, the voter wants to cast his or her vote accurately, privately, with minimal wait, and with absolutely no hassles. The mission of the polling place should be to satisfy its customers, spending the minimal amount of resources needed to do so.

We believe that polling place service can be made better, possibly lowering lines, by reorganizing staffing.

The polling place can be viewed as a queuing system, comprised of a series of queues. Voters arrive at the polling place and first enter a queue at which they get authorized to vote, by means of a check on their registration. If there were a paper ballot, the voter typically would receive it at this point. Also, there might be an opportunity for education on the mechanics of filling out the ballot or of operating the voting equipment. The voter then enters a second queue to wait for a voting booth to vote. The voter then goes to a final queue at which he or she deposits the ballot (e.g., an optical scan machine) and checks out.

Three important characteristics of this system are as follows.

First, the arrival rate to the polling place varies dramatically over the course of the day. There are three major peaks—early in the morning, the lunch hour, and early in the evening after work.

Second, poll workers are primarily volunteers, who work the entire day, from when the polls open (typically 7:00 a.m.) to when the polls close and the votes are tabulated (typically 8:00 p.m.–9:00 p.m.). The majority of poll workers are elderly persons who have retired from the work force.

Third, voting is not a frequent occurrence, and voters have limited experience with the process. A regular voter might vote at most one to three times a year. A non–regular voter might vote once every four to eight years.

Typical polling place problems are these: First, the voter has to wait too long to vote. Second, the voter goes to the wrong polling place or ends up in the wrong precinct within a multi-precinct polling site. Third, the voter is not on the registration list. Fourth, the election authority has difficulty in recruiting poll workers.

We address some tactics that should be explored by local election officials, to improve polling place practices respecting (1) the arrival process, (2) authorization to vote, (3) voter education, (4) staffing practices, and (5) continuous improvement.

Arrival Process

First, make sure the voter knows where his or her polling place is located. Send cards to voters that indicate their registration status and where they go to vote. There could also be a public information campaign to let people know when they should expect a registration card and what to do if they do not receive one. Furthermore, an incentive can be given for using registration cards—you go to a shorter queue if you bring your registration card. The county could post on the Web information on where one votes.

> *A Provocative Scenario:* It is 2002, because of long lines at the polling places in a major city, the city election office decides to leave the polling places open one extra hour. You, the reader, are standing in that line. The state courts close the polling places. You are denied access to vote.

Second, at the polling place, make sure the voter knows where to go. Polling places with multiple precincts need to have clear signs indicating where the voter should go; for instance, at each entry there should be a map indicating the precincts and directions for which line to join.

Third, encourage voters to vote during off-peak hours. Voters should be informed prior to the election about anticipated congestion during peak hours. On Election Day, real-time information on waiting times at the polls could be reported throughout the day, on radio, TV and the Web.

Fourth, encourage early voting, as available. This also will help alleviate congestion during the traditional Election Day.

Authorization to Vote

First, make sure the registration lists are as useful as possible. The various automated practices that update the registration lists should be examined, as we discussed previously in "Registration."

Second, try to deal with registration problems locally. Provide as much information as possible to each polling place. For instance, suppose that each precinct had a lap top computer with the entire city's registration list on it, and/or computer network access to the central files. The local precinct should be able to quickly tell an individual whether or not they are on the city's list and where they may vote.

Third, use provisional ballots. Determining the registration status or legitimacy of some voters may require an investigation. Such an investigation is potentially time consuming and very disruptive to do in real time, perhaps slowing the whole system down and impacting many other voters. The official in charge of a polling place should have the option to let the voter in question vote with a secure provisional ballot, but in such a way that the registration status can be investigated and resolved after the polls close.

Voter Education

First, make sure the voter is prepared before entering the booth. Some fraction of voters will arrive at the polls not knowing for whom or what they wish to vote nor how to vote. A sample ballot should be printed in newspapers and made available on the Web prior to Election Day. In cities with many different ballots this may be difficult, but publishing a full-page sample ballot would probably help many voters. Some jurisdictions now maintain Web pages that allow voters to type in their addresses and see where their precinct is located. Including a sample ballot tailored to each precinct could enhance such database applications.

To address voters who come unprepared for deciding for whom to vote, efforts should be taken to make voters familiar with the ballot and ballot format. Mock ballots should be available at the polling place for voters to review prior to voting. The voters should be encouraged to review ballot questions before entering the voting booth. Possibly they could be given an incentive to prepare a mock ballot before going to the booth. Laws that prohibit voters from taking mock ballots and similar aids into polling booths should be reexamined.

To address voters who are unprepared for how to vote, the polling place must provide just-in-time training and education on an as needed basis. The polling place should have provisions in hand to identify such voters and to provide the requisite training quickly and without disruption to the rest of the flow. For instance, any voter who asks for help could be brought to an instructional area, where the voter can learn the steps required to execute a vote. This may require hiring additional poll workers at peak times.

Second, keep everything as simple, visual, and self-explanatory as possible. Given the limited experience most people have with voting, there is not much opportunity for familiarization or learning, so all operations and processes should be as simple as possible, requiring minimal explanation.

Third, maintain continuity. For the same reason as above, changes in process should only be made when they will result in a long-lasting operational improvement.

Fourth, train poll workers to be service agents for the voters. The poll workers must view their job as being there to assist voters to cast their votes accurately, with privacy and dignity. They need to be able to identify voters who might need help, and to deliver this help with respect and efficiency.

Staffing Practices

First, consider multiple shifts for precinct workers. The current practice is to have one shift, often running from 6:00 a.m. to 9:00 p.m. or 10:00 p.m. The average age of poll workers is beyond 65. Not surprisingly, it is hard to recruit workers.

One might split the day into two eight-hour shifts. This requires finding and training twice the number of poll workers. But it should expand the pool from which to draw and should result in a more alert work force.

One might also consider shorter shifts to handle the peak hours, as is done with many service operations. For instance, there could be a three or four hour shift for the early evening. This would provide flexibility for varying the staff level over the day, corresponding to how arrivals vary over the day.

Second, expand the pool of potential precinct workers. State laws often require precinct workers to be registered voters within the precinct. Such requirements should be reexamined. One promising source of potential precinct workers may not be eligible to vote at all—high school students. Some states already allow high school students to staff polling sites, through their community service programs. Such programs may not only help address short term staffing problems at polls, but may engage young people in the electoral process at an earlier age.

Continuous Improvement

Every polling place should collect data on its operations so as to assess its performance and identify opportunities for improvement. For instance, a polling place might collect data on arrival of voters over the course of the day, waiting times, time to cast a vote, complaints, number of voters requesting help or education, registration problems and how they were resolved, and spoiled ballots.

Absentee and Early Voting

Nationwide, fourteen percent of ballots in 2000 were cast outside of traditional polling places, either through absentee ballots or early voting. This contrasts with 1972, in which no state allowed early voting and only four percent of voters cast an absentee ballot. The 2000 election witnessed the first instance of a state (Oregon) conducting its presidential election solely by mail. In six other states (Arizona, Colorado, Nevada, Tennessee, Texas, and Washington), the fraction of ballots cast before Election Day (by absentee or early voting) exceeded twenty-five percent.

The most important formal features of absentee ballots is that they are generally cast before Election Day and delivered to the local election authorities by mail. Originally, absentee ballots could be requested only for cause. This is still true in most states. Justifiable causes typically include travel outside the voting jurisdiction on Election Day, service in the armed forces, illness or disability, and religious restrictions.

Over the past quarter century, many states have relaxed access to absentee ballots, allowing absentee ballots to be issued on demand. One example is California. Since 1978, any registered voter may apply for an absentee ballot between seven and twenty-nine days before an election, for any reason, including simple convenience. In 2000, nearly a quarter of California's general election ballots were cast absentee.

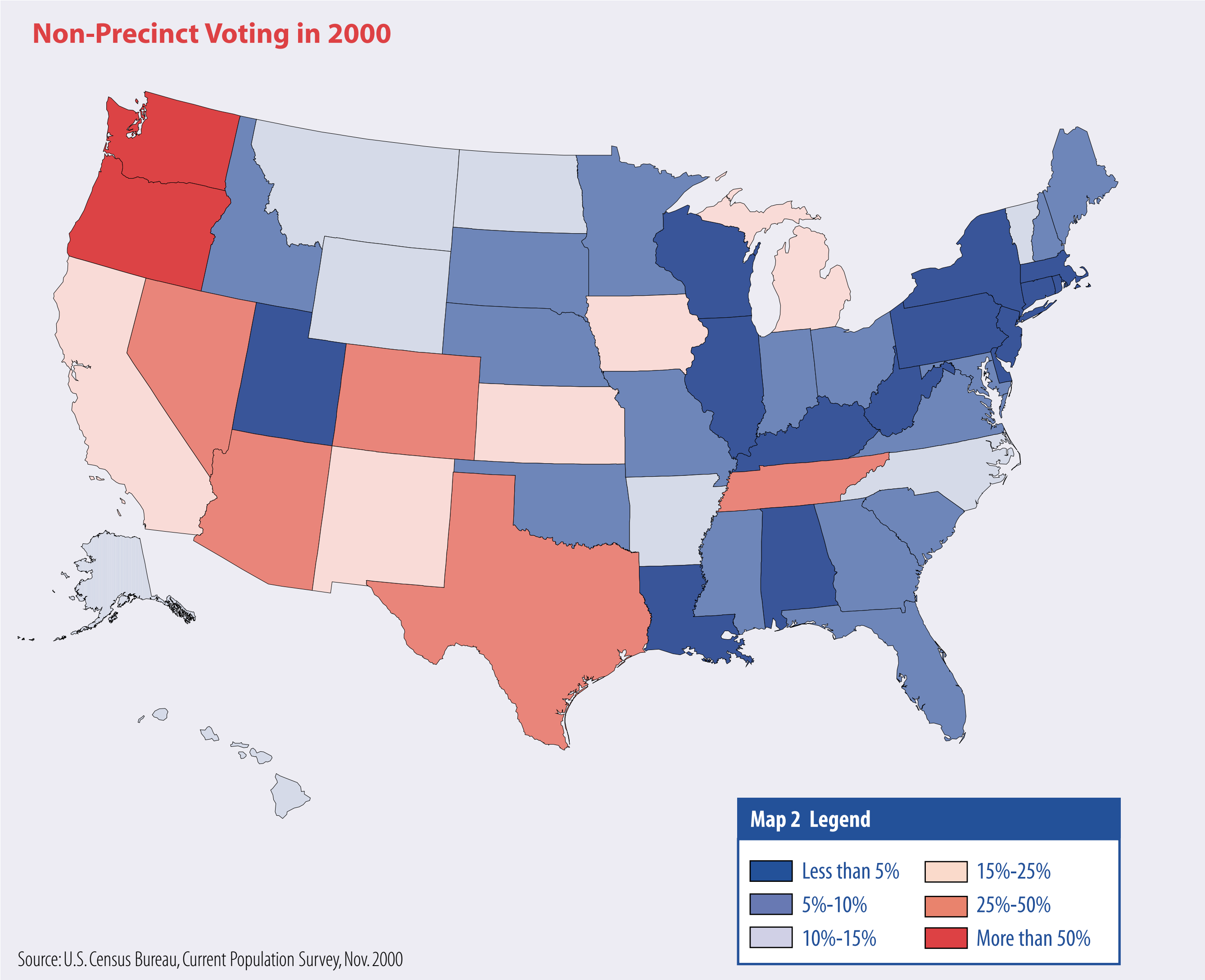
RECOMMENDATION

- Restrict or abolish on-demand absentee voting in favor of in-person early voting.
- Second, establish uniform reporting of absentee and precinct voting results.

In the 1970s and 1980s, states began experimenting with new types of voting away from neighborhood precincts. These modes formally share many characteristics with absentee balloting, but have been implemented for new reasons: namely, for the convenience of local residents who are not out of town on Election Day. These techniques are *mail voting* and *early voting*.

Voting by mail can be thought of as making mail-in absentee voting mandatory. It operates at the initiative of election officials, who mail ballots to all registered voters, who then return the ballots to the court house, most often by mail. Nevada is credited with conducting the first election solely by mail in 1960 local elections. California followed suit; San Diego held the first large-scale election, a local referendum, entirely by mail in 1981. Soon thereafter Oregon adopted a law allowing vote-by-mail, first covering only local elections. In 2000, Oregon became the first state to conduct its general election entirely by mail. Currently at least sixteen states (Alaska, California, Colorado, Florida, Kansas, Minnesota, Missouri, Montana, Nebraska, Nevada, New Mexico, New York, North Dakota, Oregon, Utah, and Washington) allow vote-by-mail in at least some elections, although no other state has moved nearly as far as Oregon.

Early voting can be thought of as stretching Election *Day* into an Election *Period*. States that have adopted early voting provisions generally make their election



ballots available to all registered voters a couple of weeks before Election Day. How and where votes are cast varies. Most states allow voters to travel to the county courthouse to vote in person, regardless of where their neighborhood precinct is located. A few states, notably Texas, allow the establishment of satellite voting sites in government buildings and public places like shopping malls. States with early voting provisions in 2000 included Alaska, Arkansas, Colorado, Kansas, Nevada, New Mexico, North Carolina, Oklahoma, Oregon, Tennessee, and Texas.

Voting absentee, early, and by mail have grown steadily since the early 1970s, accelerating their growth since the mid-1990s. Voting away from neighborhood precincts has also tended to be more of a Western phenomenon. (See Map 2.) However, legislative changes and the strategic activities of political parties have also led to an eastward spread in non-precinct voting.

What Could Be Gained by These Techniques?

Arguments in favor of these three forms of voting all share a set of common aims.

First, they are all intended to improve convenience for established voters. Established voters, who are the constituents of most election officials, live busy lives and

have experienced service improvements in the private sector affecting operating hours and procedures to accommodate complications of modern life.

Second, because these techniques make voting more convenient, supporters contend that they should also decrease barriers to participation that confront current non-voters. With the barriers to participation lowered, voting turnout should increase.

Third, many (though not all) of these techniques hold out the promise of reduced costs, at least in the long run. All-mail elections particularly eliminate the need to staff thousands of neighborhood polling stations, with their expensive equipment and staffing headaches. Finally, all of these techniques promise greater administrative control over elections—not because they simplify elections per se, but because they provide more time for election administrators to handle the increasingly complex problems that arise in running elections.

What are the Dangers of These Techniques?

Five dangers are usually cited in opposition to early, absentee, and mail voting. The first is coercion. The two primarily mail-in techniques (absentee voting and all-mail voting) are fundamentally not secret ballots. Although laws prohibit coercing absentee voters, the physical protections against coercion that exist in a neighborhood precinct—such as secrecy booths and buffer zones around polling places—are lacking. Concerns over coercion are especially acute in settings where voters may be reliant on care givers, as in nursing homes.

A second concern is fraud and security. Mail-in techniques rely on the delivery of ballots in unsecured modes. Mail channels to and from the court house are generally unsecured. The primary assurance that the intended voter returned a legal ballot is a signature on an affidavit that accompanies the returned ballot. Therefore, the integrity of the voting rolls depends on the signature verification skills of local election officials.

The third concern is accuracy. Problems that voters might have in using voting technologies in precincts may be exacerbated in the mail-in settings. For instance, when punch cards are used in the absentee setting, the punch card ballot is often attached to a Styrofoam backing. A paper booklet with candidates and issues accompanies the ballot. The voter notes the number next to the candidate or yes/no position, locates that number on the pre-scored ballot, and punches through the number. Going back-and-forth between the booklet and the ballot introduces even more opportunities for mis-marked ballots than when punch cards are used in the precinct. Punch cards are especially confusing when the number associated with a proposition clashes with the hole number on the ballot card.

Speed is a fourth concern with non-precinct voting methods. As the fraction of votes cast via the absentee process grows, concerns over delays in counting absentee ballots have also grown. In Washington State in 2000, for instance, over half of all ballots were cast absentee. The slowness of the count in Washington meant that recounts in two very close races, U.S. Senate and Secretary of State, were not ordered until three weeks after Election Day. Recounts in less visible local races were similarly delayed.

The fifth and final concern is that these techniques all reduce or eliminate the ceremonial aspects of voting.

How Have These Techniques Fared?

Available data and scholarly assessments support those who urge caution in expanding opportunities for voters to vote away from neighborhood precincts. This is particularly true of mail-in methods, both early and absentee voting.

There is no evidence that liberalizing absentee voting laws or enacting early or vote-by-mail schemes has increased voter turnout dramatically. Oregon is a case in point. Oregon's turnout in 2000—the first year of vote-by-mail for the general election—measured as a percentage of the voting age population, was up 3.5 percent over 1996, compared to the nationwide increase in turnout, which was 2.1 percent. However, sixteen states and the District of Columbia had turnout increases in 2000 that exceeded Oregon's. The story is less favorable in Texas. In every presidential election year since Texas began early voting in 1988, the voting turnout increase in Texas has been less than turnout increases nationwide. Early voting in Texas has therefore been associated with a net decrease in voter turnout, compared to the nation.

Research at the University of Michigan has documented that the most important effect of the Oregon vote-by-mail system has been to increase the convenience to established voters, not to induce many non-voters to the polls.

A Provocative Scenario: It is 2002, and in a tight race for the U.S. House, a voter complains that she did not receive her absentee ballot. The town election official says that the citizen actually voted. An investigation reveals that an organization applied for and filled out hundreds of absentee ballots of people on the "inactive" registration list. The election ends up going to the courts.

Similar results have followed from research on Texas early voting and absentee voting generally. The one exception may be turnout in local elections.

Research on the turnout effects of absentee voting are especially troubling in light of controversies in three Florida counties in 2000 over partisan use of ambiguous absentee voting laws. There, lawsuits were filed in Bay, Martin, and Seminole counties, alleging irregularities with absentee ballot applications that party activists had sent to masses of voters. Leaving legal issues aside, the Florida episode reminds us that research has identified one condition under which absentee ballot laws increase turnout: when they are sufficiently ambiguous or liberal to allow partisan forces to use them to boost the turnout of party loyalists.

Lacking widespread and consistent data about electoral administration, it is difficult to document whether other gains from out-of-precinct voting have in fact materialized. For instance, the claim that all of these techniques provide a more manageable environment for dealing with the complexities of election laws seems true on its face. Yet voting jurisdictions rarely report reliable cost data. They also rarely report data such as the percentage of absentee ballots rejected due to irregularities. Without data such as these, assessing the administrative effectiveness of these techniques in new settings is virtually impossible.

A lack of data also impedes understanding whether current voting technologies are more or less error-prone in these settings. The spotty evidence that exists is inconsistent. For instance, in Idaho in 2000, the residual vote rate for absentee ballots was substantially higher among counties with punch cards (3.0 percent in-precinct vs. 4.6 percent absentee) while being roughly the same among counties with optical scanners (3.9 percent vs. 4.0 percent) and paper ballots (2.8 percent vs. 3.0 percent). In Florida, counties that separately reported election returns for absentee ballots generally showed no difference in the residual vote rate between absentee and in-precinct ballots. Likewise, in Washington State the residual vote rate is unrelated to the fraction of ballots cast in counties that are absentee, once the size of the county is controlled for.

In New York, on the other hand, the residual vote rate in 2000 for absentee ballots among a sample of counties was 4.4 percent, compared to the residual vote rate in those counties of 0.9 percent on the in-precinct lever machines. When Oregon instituted statewide vote-by-mail in 2000, the residual vote rate went up statewide slightly compared to 1996, but the increase was significantly higher in counties that relied on punch cards (2.0 percent in 1996 vs. 2.3 percent in 2000) compared to counties with optically scanned ballots (1.2 percent in both years).

We performed a simple analysis to see if there was any correlation between the rate of absentee voting in counties and the rate of uncounted, unmarked, and spoiled ballots in 2000. The correlation was slight, and negative.

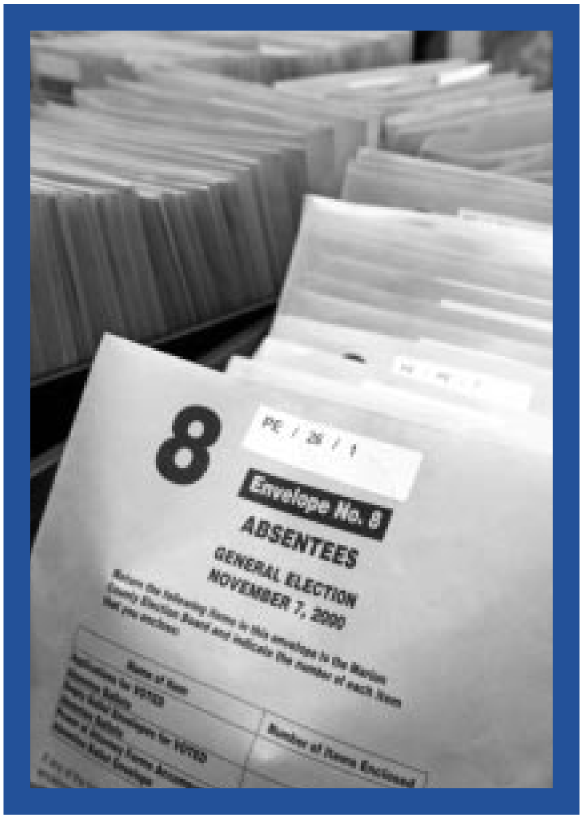
Speed of reporting is another concern that has arisen as absentee laws have become liberalized. Mail delays have always been a problem with absentee voting procedures. When the fraction of ballots cast absentee is small, these delays rarely have significant consequences. However, as the fraction of votes that are absentee grows, concerns over delays in counting ballots also grows.

Speed of the count is a dimension on which Oregon's vote-by-mail system offers clear advantages. By mailing out ballots to all voters and requiring that they be returned (by mail or in person) by 8:00 p.m. on Election Day, the Oregon system eliminates the need to wait for absentee ballots to trickle in after Election Day.

In short, absentee voting systems do not seem to have made great improvements in turnout. But they have also not produced higher residual vote rates.

The most important concerns raised by these procedures focus on increased opportunities for corruption. Indeed, the most prominent recent election fraud court cases involved absentee ballots—Dodge County, Georgia in 1996 and Miami in 1997. Dodge County involved two competing candidates for the Democratic nomination for the county commission bidding against each other for absentee ballots inside the county courthouse. In Miami, fraud so pervaded the absentee ballots that an appellate court eventually threw out all absentee ballots and declared a winner based solely on the machine vote.

We have no systematic measures of fraud, but fraud appears to be especially difficult to regulate in absentee systems. In-precinct voting or "kiosk" voting is observable. Absentee voting is not. The prospect for coercion is increased with absentee voting on demand.



Recommendations

First, restrict or abolish on-demand absentee voting in favor of in-person early voting. The convenience that on-demand absentees produces is bought at a significant cost to the real and perceived integrity of the voting process. On the face of it, early voting can provide nearly equal convenience with significantly greater controls against fraud and coercion. Traditional absentee procedures for cause are still valuable for the limited situations they were originally intended for. States should return to those practices.

Second, establish uniform reporting of absentee and precinct voting results. States should require that election jurisdictions report, in a uniform manner, data necessary to diagnose the accuracy and efficient administration of non-precinct ballots, as well as data necessary to ensure citizens that such procedures are no less accurate, error-prone, or fraud-prone than in-precinct methods. These data include (1) separate election returns by method of casting a ballot (e.g., in-precinct, absentee, early), (2) cost accounts associated with administering different modes of balloting, and (3) statistics concerning the number of challenges to ballots and the reasons for excluding ballots from counting. Clear reporting will allow states to assess the effectiveness of absentee and early voting and to identify potential problems and irregularities.

Ballot Security

Security is as important as reliability in guaranteeing the integrity of the voting process and public confidence in the system. People do not use things in which they have no confidence. Losing confidence in elections means losing confidence in our system of government. Security systems maintain our confidence that elections work. Voters should not have to worry about rigged machines or illegal voters.

Stolen ballots, illegal voters, and stuffed ballot boxes have long been concerns in the U.S. They were the basic tools of machine politics in the nineteenth century. Cases of vote fraud persist to this day. Some of the more ingenious methods for defrauding elections and some of the more entertaining stories involve stolen ballots.

In Maine in 1998, two legislative aides pleaded guilty to breaking into a ballot storage area in the Maine State House and tampering with the ballots being stored pending a recount of two close elections for the state legislature. When ballot tampering of this sort is discovered, sometimes the only remedy if the tampering affected the outcome of the election is a "revote." Revotes are a bad way of settling contested elections because the election is no longer the same. For example, if a single seat determined control of the legislature, then the revote would be not just about this seat, but about which party would govern the legislature. Worse still are the cases of fraud that we never discover; then the election does not reflect the public will.

RECOMMENDATION

- Move away from complex, monolithic machines.
- Make source code for all vote recording and vote counting processes open source and source code for the user interface proprietary.
- Make recording software openly auditable in the same mode that is used to conduct the counts.
- Adapt equipment so that *voters* can create a record of the vote that they can examine directly, and that can be used to audit equipment and elections.
- Conduct audits of votes and equipment, even without a recount.
- Design equipment that logs all events (votes, maintenance, etc.) that occur on the machine.
- Train election officials in the interior workings of their voting equipment.
- Delay Internet voting until suitable criteria for security are put in place.

The Maine case had an ironic twist. The defendants did not get the count right. Their efforts to alter the number of ballots in favor of Democratic candidates failed because the absentee ballots from these races had not yet been tallied. Although this case of tampering had no effect on the outcome of the race, it did negatively affect the citizens of Maine's confidence in their electoral process.

Large-scale fraud—involving many voters or significant changes in the final tally—is more important than small-scale fraud involving a handful of ballots or voters. Small-scale fraud amounts to grains of sand added to one side of a scale. The U.S. historically has had problems of large-scale fraud. Machine politics in the nineteenth century involved coordinated, large-scale activities to alter vote tallies, to cast illegal votes, and to destroy ballots. Such coordinated activities could alter thousands of ballots.

Small-scale fraud is also a concern in close elections, as the example from Maine demonstrates.

We distinguish two broad types of security problems: manipulation of voters and tampering with the recording of votes and counting mechanisms.

Manipulation of voters encompasses a range of activities. Your vote should be your vote: it should not be coerced or corrupted by someone else. And, every person should count the same: people are not allowed more than one vote in our society. Someone, such as an employer or union official, might coerce the voter to vote a certain way. Someone might try to purchase a voter's ballot. Someone might try to vote more than one time. Someone from outside the community might come to vote in the community. Such manipulations involve the individual who casts the ballot.

The U.S. has developed a set of procedures to prevent manipulation of voters. The most important are the secret ballot and voter registration. Also, coercion, vote buying, and other forms of manipulation of voters are felony crimes.

Secrecy and registration are not themselves technological solutions, but they do place important constraints on the development of voting equipment. The secret ballot is a particularly troubling constraint because it means that, at least with current equipment, voting is receipt-free.

Tampering with the mechanisms for recording and counting votes represents a second type of security problem. Votes might be stolen or destroyed. For example, it is easy to jam a voting machine so that the counter in the back of the machine does not register the votes cast for a particular candidate. Votes might also be added to the count—stuffing the ballot box. Before the election, someone might "warm up the machine" by pulling the lever a few times. These problems do not involve the individual who casts the ballot, but someone else, such as a poll worker, an election officer, or a manufacturer.

Many solutions for tampering with the mechanisms for recording and counting votes involve technology. Technology typically raises barriers to a security breach. Increasingly secure ballot boxes and machines have been devised. A common way of increasing security involves multiple locks, with keys controlled by the election administrators. Many systems have redundant recordings of the vote. Some jurisdictions require that the system have an "audit trail," a separate recording of each vote that can be used to audit the performance of the machine. In addition, there is now a protocol for testing the integrity of tabulation software, though this procedure is voluntary and requires only limited testing.

Beyond technological protections, election administration provides a variety of protections against security problems. Poll watchers, who represent parties or candidates, can observe the goings on at each polling

A Provocative Scenario: A programmer at SlickVotingMachines Corp. adds malicious code to a DRE (Direct Recording Electronic device) machine for the California 2004 Presidential election, so that every fiftieth vote for a Republican candidate is changed to a vote for the corresponding Democratic candidate. This only happens when the machine is in "real" mode as opposed to "test" mode, so the election officials never discover the fraud during their testing. The electronic audit trail made by the DRE machine is also affected, so "recounts" never discover anything amiss.

place and report any problems. In many states, counting is conducted publicly, to guard against altered or irregular tallies. Canvassing boards in some states check counts. In many states, police are assigned to each polling place; state and local police often oversee the transportation of ballots.

The security system for voting that has evolved in the United States has several important strengths that must be preserved as new technology is developed and deployed.

First, we have an *open process*. Anyone can observe the activities inside the polling place, so long as they are not disruptive and do not try to persuade people to vote for a particular candidate, party, or position while in the polling place. Poll watchers frequently catch problems. In the 2000 general election in Boston, poll watchers noticed that the precinct wardens incorrectly recorded the counts for ballot propositions. The error retrieved 30,000 votes for at least one ballot question. Outside of polling place operations, it is important to have other parts of the process as open as possible to catch problems ranging from the design of equipment to the purging of registration lists, to the certification of the vote.

Openness needs to be preserved, and this principle should be embraced throughout the voting system, including in the development of equipment.

Second, the process involves *many people* and many different interests and *separation of privilege*, or *separation of duty*. The local election office manages equipment and counting of votes. However, within each locale there are many people watching the casting and counting of votes. The state governments certify the votes, and often oversee recounts. The vendors make the equipment, and have a stake in making sure that no one tampers with their equipment. No one person or level of government controls all elections. In fact, this is one important advantage to decentralization. Having many people observing each other provides an excellent set of checks. Decentralization guarantees many eyes on the process.

We need to keep as many people and organizations as possible involved in the administration of elections and in the management and development of equipment. We should not give an individual or computer system more control over the process than he, she, or it needs to do his, her, or its specific function.

Third, most equipment does, and all equipment should, provide *redundant trusted recordings*. Having several recordings of voters' intentions allows a full audit of any election. Typically we only audit close elections, when a recount has been requested. Some jurisdictions and some vendors will audit equipment at random to learn more about what works and what does not, and to try to identify problems that might exist throughout the system.

For reasons of security, we should require redundant recordings of all new equipment, and we should move away from equipment that does not allow for redundancy.

Fourth, election administration is a *public process*. U.S. elections are administered by public officials rather than by private agencies. Because elected officials are ultimately responsible to the public, we the voters have a higher degree of control over their performance. Because voting is a public good, public control is essential.

We strongly believe that election officials should have full control over all equipment used in elections. They may contract out for service and storage and even lease equipment, but election officials must be able to inspect all aspects of equipment at any time.

Electronic Voting and Security

We are concerned that we are moving away from these general principles that help guarantee the security and integrity of voting.

We are in an era of electronic voting. Almost two-thirds of all votes in 2000 were counted using electronic tabulation, including computers, punch cards, scanners, and DREs (Direct Recording Electronic devices). Hand-counted paper, despite its advantages and wide use in Europe, is infrequently used in the U.S. Electronics are increasingly used to record votes. DRE machines require that voters generate votes and record votes electronically. Scanners and DREs are where the growth in the industry is occurring.

The computerization of election systems introduces significant security risks but also significant opportunities for fraud prevention and detection. For example, electronic transmission of vote tallies, so long as that transmission is secure, means that we do not have to have police ferrying ballots around on election night.

We see the following security risks associated with electronic voting.

First, we are losing openness. Electronic voting machines are completely closed. We can no longer observe the count.

Second, we are losing the ability for many people to be involved. Election equipment tries to do it all. A single computer system generates votes, records votes, counts votes, and produces the final tallies. Without openness, we lose the advantage of having many eyes on the count.

Third, separation of privilege is lost. We are headed toward monolithic systems—one machine that does it all. This risks vesting too much control over the system in the vendor's hands or in the hands of any hacker who can get inside of that monolithic system.

Fourth, many electronic devices lack redundancy and true auditability. To audit a voting machine, one needs a redundant recording of what the voter intended. There is the initial recording that the electronic machine made, but there must also be a *separate recording* against which the machine recording is tested—an audit trail. The problem for many electronic devices is that their audit trails are simply another recording of what the machine recorded. Roy Saltman,

a leading expert on voting technology, has long advocated that the true standard of auditability is that the audit trail is produced by the voter and not by some intermediary machine. This is an important insight. It is the only way to guard against a fraud scheme in which the code occasionally drops votes; it also protects against machines that accidentally lose votes, say because of a power surge.

Fifth, we are losing public control over voting equipment. One worry with electronics is that they are sufficiently complex machines that administrators cannot inspect the inside of the devices. Even the independent testing authorities have difficulty completing speedy certification reviews of the hardware and software on new electronic devices owing to the increased complexity of the hardware and software. Administrators must trust manufacturers, as must the voters. We prefer transparent voting systems where the operations are observable and verifiable by anyone.

All of these problems are solvable. We strongly believe that the principles of openness, many eyes, separation of privilege, redundancy, and public control must guide the design of electronic equipment.

First, we should move away from complex, monolithic machines. It is very difficult to design secure systems that must meet a complex set of requirements. Extreme simplicity is strongly recommended. We think that a better approach is to have a very simple electronic vote-recording device that is separate from other parts of the system. A machine used to prepare a ballot can be as complicated as one likes, and could even be used for other things when elections are not happening, such as classroom instruction.

The vote-recoding device is the critical device in securing the vote. When the vote is recorded is the moment that the voter loses control over the vote. All of the problems of tampering emerge at this moment. If the vote recording is secure, then we can truly heighten the security of the entire system.

What must be secure are the devices that record and count, not the user interface that generates ballots. The device that records votes must be very secure. And it should not be expected to do anything other than record votes. It should be a *very simple* machine, nothing as complicated as a personal computer. This suggests that the industry and administrators use separate devices for recording and for generating votes. That will be explored in the final section of this report.

Second, the source code for all vote recording and vote counting processes must be open source. The source code for the user interface can and should be proprietary, so that vendors can develop their products. There are many protocols for open source. We think that a national commission consisting of experts on security from outside the voting industry, including other industries such as banking and Internet security, should determine the appropriate protocol for open source in the voting equipment industry.

Third, all recording software should be openly audited in the same mode that is used to conduct the counts. "Test" modes should be eliminated. Counting and recording devices should be "modeless." The test mode feature is a security vulnerability because it creates a way to cover a hack. To truly reclaim the openness of the count, interested parties (candidates, party organization, groups, etc.) should be allowed to inspect the software as it is formatted for Election Day. All interested parties should be satisfied that votes will be counted appropriately.

Fourth, equipment should be adapted so that *voters* can create a record of the vote that they can examine directly, for the sake of auditing equipment and elections. This might require some sort of simple paper recording that the voter can check and submit separately.

Fifth, we recommend audits of votes and equipment, even without a recount. Total votes and votes for each office and proposition should be logged on all equipment and recorded electronically. Election officials should inspect these recordings to detect irregularities on particular machines or at particular precincts. In addition, election officers, especially in larger jurisdictions, should randomly choose a small percent of the machines (say one percent) each year for thorough inspection.

Sixth, all equipment should log all events (votes, maintenance, etc.) that occur on the machine. The information on the log should include what was done, when it was done, and who authorized the activity. The election office should keep those logs.

Seventh, all election officials should be trained in the interior workings of their voting equipment. They should only use what they can understand and check. This training is perhaps best provided by vendors, and may be a requirement of purchase.

Finally, we are concerned with where computerized voting is heading. Voting on a personal computer is a step away from voting on the Internet. Remote Internet voting poses serious security risks. It is much too easy for one individual to disrupt an entire election and commit large-scale fraud.

Cost and Public Finance of Elections

Elections represent an organizational challenge in a country like the United States, with nearly one quarter of a billion eligible voters scattered across over 3,100 counties in fifty states. To meet this challenge we have developed a large bureaucracy—or rather, thousands of small bureaucracies. A small but vital group of private vendors and service providers produce the equipment, software, and peripherals to collect, process and count millions of individually marked ballots. These firms also develop software for voter registration and other aspects of election administration. We refer to this public/private partnership of election producers collectively as *the election industry*.

This industry produces a service. Do we spend an appropriate amount for this service? Or, as is common with public goods, do we purchase too little service in support of elections?

One answer is that we *should* spend more. Elections are fundamental to our society, and the U.S. promotes democracy around the world. The operation of elections in the U.S. should be given a very high priority. Today, elections receive about as low a priority as any government service.

Perhaps this is answer enough—the U.S. should change its priorities.

We do not give elections a high priority, and we must consider how this industry manages to provide the services that it does under existing financial constraints. Within these constraints, are improvements possible?

Here we take a harder and more analytical look at how we provide for elections in America.

Even the most basic facts about the cost and finance of elections in the United States are unavailable, and the most basic questions remain unexamined. It is not known how much we spend on election administration overall in the U.S. each year. It is not known on what funds are spent. There has been little analysis of how and how well local governments provide election services. Each of us has some sense of what we get—a stable and successful democracy. But there are clearly problems that can be remedied. How much will improvements in this system cost?

RECOMMENDATION

- The federal government, working with state and local governments, needs to develop standard methods of accounting for election expenses and standard reports that are made publicly available.
- The federal and state governments should offer significant matching funds for upgrades to replace voting technologies—such as punch cards, lever machines, centrally counted optical scanning, paper, and some under-performing DREs—that are clearly dominated by existing equipment.
- The federal and state governments should pay for the maintenance of voter registration databases maintained at the state and local levels.
- The federal government needs to maintain a publicly available database of election expenditures.

In preparing this report, we have collected data to try to assess some of the fundamental questions. How much do we spend on elections, and on what? To make decisions about the value of additional expenditures, more thorough study will be needed.

Inputs and Outputs of Elections

What is output? As is often the case in service industries, including the delivery of election services, this is a bit slippery. Output can be defined in several ways: customers (voters) served, the functioning of the system supported (democracy), and many measures in between.

Even among services, the output of the election industry is unusual for a number of reasons, three of which are particularly noteworthy.

First, it is one of a handful of industries that is financed entirely with public funds. Remarkably, the public finance issues have never been investigated systematically.

Second, the output, valid ballots, is unpriced and untraded in the marketplace (or at least that is *supposed* to be the case). Moreover, it is difficult to place an economic value on valid ballots, much like valuing the protection of an endangered species or a national treasure. It is a classic public good problem, and different individuals will place different values on it. The total value to society would require us somehow to aggregate these individual valuations.

Third, the output is also an intermediate product, with the "real" output being the electoral outcome (winning and losing candidates and propositions) and, ultimately, public policy.

By some measures we are doing impressively well. The electoral process has survived civil and international wars. It has expanded dramatically to include many new categories of people over the past two hundred years without disrupting our form of government. In 2000 alone, over 100 million people voted.

Our report emphasizes a different output: the quality of service. And we have one such concrete measure: lost votes. We must lower the rate of lost votes to an acceptable level.

How much is it worth paying to have a marginally more honest and accurate election? We do not yet know the answer to this question. Instead, we can assess how much the existing level of quality (vote loss) costs.

To compute costs, we consider "What are inputs?" This is easy to answer in principle, but hard in practice, because of poor data. Basically, the inputs are labor, maintenance, storage, and acquisition of equipment, supplies (such as printing), information systems, and rental of space (often free). Cost figures are available usually at the county level in one of two forms: annual election budgets and general election operating costs.

A common measure of election cost is given by cost-per-vote, or alternatively, cost-per-valid-ballot. This measure does not seem appropriate in many circumstances because of the varying number of ballot items, differential turnout rates ("potential votes"), and other quality issues. It is, however, the one we have the most information on, and it is useful so long as quality does not vary too much with the key independent variables (like machine type or number of ballot items).

A Provocative Scenario: It is 2004, and little has been done to improve the voting system. A dip in the economy led to belt-tightening in state and local budgets. Education and roads were spared; new voting equipment and registration systems were put on hold. In close elections around the country, media scrutiny once again reveals that the problems of 2000 remain unfixed.

Production costs for vendors are not available, and there are significant development and marketing costs that are bundled into the equipment contracts.

How Much Do Elections Cost in America?

Surprisingly, there is no ready answer to this question.

The reason? Election expenditures are sufficiently small that they do not make the list of important activities reported in the Census of Governments, which is the annual report by the U.S. Census Bureau about what states and local governments spend on their functions. That, in itself, is some indication of the low level of election expenditures in the United States. The smallest general expenditure category presented by the Census of Government for the *Statistical Abstract of the United States* in 2000 is $14 billion on solid waste management.

Accounting practices also contribute to the difficulty of measuring election administration expenditures. For example, some counties have very detailed budget reports, including space rental, printing costs, telephone and postage, pollworkers, etc., while other counties offer no budget breakdown at all.

Overall Spending

We canvassed county and state governments from around the country to find out how much they spend annually on elections. Based on annual budgets from various states, we estimate that the *counties* spent approximately $1 billion on election administration (excluding some large procurements of new equipment) in 2000. That was for a presidential election year, so actual operating costs are somewhat lower in other years. With slightly over one hundred million voters, that works out to about $10/voter. States and cities also contribute to the financing of elections, but at a lower level than the counties.

We sought other estimates to corroborate ours and found them to be in the same neighborhood—approximately $1 billion, perhaps slightly more. For instance, an analysis of election administration in California (commissioned by Ernest Hawkins, Registrar of Voters of Sacramento County, California) arrived at a similar projection for the U.S.

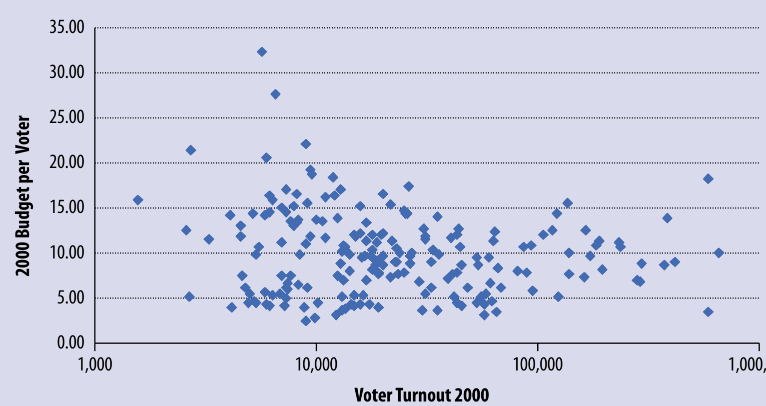
A much more in-depth census of election administration is required to give a complete picture of what is spent on election administration. We take the $1 billion figure to be a ballpark estimate. To put it in some context, counties and cities spend over ten times that amount on solid waste management and on parks and recreation.

How much is spent also depends on the size of the county. There are some economies to scale in election administration, as indicated in Figure 1, which is based on data from a survey of annual election budgets from counties in nine states in 2000.

Very small counties (less than 25,000 voters) spend disproportionately more to run their elections. This is probably not because they have more resources to spend: rural counties tend to be poorer. Above 25,000 voters, there is little evidence of an economy to scale.

FIGURE 1

ANNUAL COUNTY ELECTION BUDGET PER VOTER: 2000



Source: Caltech/MIT Voting Technology Project (from state and local sources)

Itemized Expenditures

Far more difficult is figuring out how much we spend on specific aspects of election administration—equipment, voter registration, polling place operations, and other factors. By looking at detailed breakdowns of the budgets of several cities and counties, we have been able to approximate the division of these costs into equipment purchases and maintenance, Election Day operations, voter registration, and general administration.

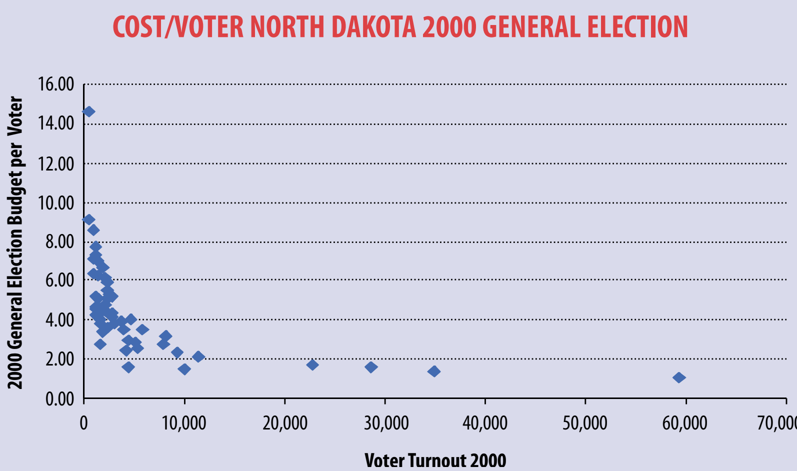
Voter registration and general administration account for the lion's share of election expenditures—roughly one-third each. That is, counties and local governments spend between $300 million and $400 million each year on their registration systems. We have learned from the voting equipment industry and from local budgets that equipment purchases and maintenance amount to approximately $150 million to $200 million annually, or roughly fifteen to twenty percent of total election administration expenditures. Election Day operations—polling place management, poll worker training and salaries, printing, and the like—are in a similar range, fifteen to twenty percent of total budgets.

On a per voter basis, these figures imply that locales spend approximately $3.50 per voter on voter registration. Local governments spend approximately $1.50 per voter to acquire and maintain voting equipment. And local governments spend about $1.50 per voter actually to run the election on Election Day. Another $3.50 per voter is spent on administrative overhead.

Economies to scale are much more evident in the operation of elections. These scale economies arise not just

because of a large fixed cost of equipment or administration. Larger counties also spend less on a per voter basis for Election Day operations. Consider the operating expenses for the 2000 general election of the counties in North Dakota. Figure 2 below graphs county size on the horizontal axis and per-voter general election costs on the vertical axis. On a per voter basis, smaller counties pay much more for Election Day operations than large counties.

FIGURE 2



Equipment Expenditures

Equipment costs are of particular concern. Today, many states and counties wish to upgrade their equipment. Some states are forcing counties to upgrade through legislation banning or decertifying punch cards. What is the fiscal impact of such purchases?

We have obtained information from some counties and vendors on the costs of acquiring equipment. There are two competing technologies—direct recording electronic machines (DREs) and optical scanners. Acquisition costs for purchasing new voting equipment are $18–$25/voter for touchscreen systems and $8–10 for in-precinct optical scanning equipment. The lifespan of election equipment ranges widely, but averages in the 15–20 year range, so that acquisition costs of current equipment would be on the order of $1–$2 per voter per year in current dollars.

A nation-wide upgrade to touchscreen DREs would cost up to $2.6 billion; a complete upgrade to scanners would cost up to $1 billion. Both figures are well in excess of what all counties currently budget for equipment (approximately $150 million).

These figures, however, seem less exceptional when we consider the lifetime of the equipment. Assuming these machines last approximately 15 years, the cost of an upgrade to DREs would run approximately $1.40 per voter per year and the cost of an upgrade to scanners would cost approximately $0.60 per voter per year.

This is well within the annual revenues generated by equipment sales. Industry sources also report that annual industry revenues are on the order of $150 million in a good year. This corresponds to $1.40 per voter per year.

This figure is in line with what counties currently spend on equipment, approximately $1.50 per voter per year. However, most counties bear the costs of purchases at one time. A purchase of DREs of $20 per voter is double the typical county's entire election administration budget.

The fiscal problem is figuring out how to finance equipment purchases over the long run.

One solution is that the states or federal government share the cost of any changes in equipment, especially if the states or federal government mandate changes. Counties cannot deal with unfunded mandates of this magnitude.

Another part of the solution is leasing. The state of Rhode Island, many counties in Maryland, and a scattering of counties elsewhere lease equipment. Leasing avoids the huge upfront expenditure for purchasing equipment, and leads to greater flexibility for upgrades. Leasing contracts—including maintenance, service, and consulting—are on the order of $1.50 per voter per year (over fifteen years), based on Rhode Island's lease-to-own agreement with Election Systems and Software (ES&S). The state has approximately 400,000 registered voters and the annual cost of the contract is approximately $0.6 million.

The Maryland Secretary of State's office recently published a report that showed leasing costs ranging from $1 to $3 per voter per year, with much of the variation attributable to differences in population density. These figures are only slightly above what other counties budget for equipment maintenance and purchases annually.

There may be some premium for leasing—that is, leasing election equipment may cost more than buying it, in the long run. However, states and counties can strike lease agreements that actually lower costs. Rhode Island's state legislature stipulated that the lease could only happen if the total cost (including service and equipment) cost less each year than maintaining the state's lever machines.

How Much Quality For Each Dollar?

Election officials like to point out a "tradeoff triangle" that reflects what many administrators and the news media view as the primary three objectives of a "good" election system. These are: (1) speed of the count, (2) accuracy, and (3) cost. Note that this ignores other criteria, such as security, ease-of-use, and accessibility.

In our view, one of these—counting speed—is misplaced. Surely this must be a secondary consideration given that the outcomes of most elections are not implemented for months. Moreover, virtually all systems have counting speeds that enable the election to be called within twenty-four hours, barring recounts or unusually close elections. In the rare cases where twenty-four hours is not sufficient, most experts would agree that it could not be done in fewer than twenty-four hours using any of the existing technologies, except perhaps those that effectively preclude any hand recount—systems without a paper trail, such as lever machines and most electronic devices. Counting speed, therefore, seems nearly irrelevant.

Perhaps more critical is *recounting* speed. Long recounts damage public confidence in the election system and open up greater opportunity for fraud.

Thus, the main tradeoff is between cost and accuracy. The two main contenders in terms of modern technology are precinct-level optical scanning and touchscreen electronic. Over a fifteen-year span, the combined operating and acquisition costs are not substantially different. Both are around $2 per voter per year.

The additional annualized cost (or savings) from choosing electronic instead of optical scanning would not be more than 10 percent of the total annual election administration costs. Thus, equipment costs are at a very reasonable level, with only marginal variations across the two prime technologies of today.

Given our most current data, there is a difference between electronic voting systems and precinct level optical scanning technology. Optical scanning has produced significantly fewer residual votes than electronics over the last decade. However, this is based primarily on data from full-face DRE equipment. Touchscreen equipment is very new and has a limited track record. As the industry improves electronic technology, the gap in the residual vote rate between these two technologies can be expected to narrow.

The Future of Voting Equipment Manufacturing

By modern standards, the voting equipment industry is small. A small number of private firms invent, develop, manufacture, market, and maintain voting equipment and election supplies for the counties. Industry estimates of annual industry revenue fall in the $150–$200 million range, or about $1 per eligible voter. This figure covers sales of new equipment, maintenance, and service (including printing of ballots, in some cases). To put this in perspective, annual sales of residential lawnmowers run into the billions of dollars, making the residential lawnmower industry more than ten times the size of the entire election industry.

In the past decade, companies involved in elections have undergone a major consolidation, leading to a more concentrated industry. The four largest manufacturers are Danaher Controls (Guardian Voting Systems), Global Election Systems, Election Systems and Software (ES&S), and Sequoia-Pacific Voting Systems. Together, they make up nearly ninety percent of the market. By far the largest of these is ES&S, which contracts with approximately sixty percent of the counties in the U.S. Very few counties contract with more than one vendor.

Because of the long shelf life of the product—twenty years or more—relationships between a county and its vendor are long-term. Contracts are negotiated each time a new equipment purchase is made, often between savvy veterans from the company sales force and county officials who rarely, if ever, negotiate any major contracts and are unlikely to have negotiated a previous contract for election equipment.

We do not expect much growth in this industry. Assuming that all counties upgrade their equipment over the next fifteen years and that one-half adopt DRE devices and one-half adopt scanners, we project that the industry will remain approximately the same size.

One perverse effect of the current push to purchase new equipment is that it may hasten the need to develop a new business model in order for firms to survive. Suppose that all counties with obsolete or inferior equipment upgrade within the coming year, so all counties have relatively new, relatively good equipment. This will kill demand over the succeeding years.

The next few years will likely be quite good for those selling machines, but the long-term prospects for this industry are not as rosy. Now is a critical juncture for firms to evaluate the service they provide and to make a serious effort to develop new ways of providing voting technology.

The voting equipment industry must adapt in order to thrive. A new business model might emphasize service over selling boxes. It might emphasize modular equipment with standard operating systems: one firm provides the machine, one firm provides the user interface, one firm provides the counting and vote transmission software.

A Federal Role in Financing Elections

The federal government and most state governments have stayed out of financing election administration. We can identify several specific ways the federal government can contribute to the public finance of election administration.

The government should finance upgrades of equipment to phase out dominated technologies (punchcards, lever machines, centrally counted optical scanning, paper, and under-performing DREs). A preferred approach would involve a gradual and on-going process for administering grants to counties and localities to help them replace deficient technology in a methodical and carefully studied way that would create options for future system upgrades or conversions.

The federal government should establish and fund an independent agency for election administration. Currently, there are significant financial constraints on the Office of Election Administration in the FEC. The new agency would perform the sort of information clearinghouse function that we see as necessary in order to establish best practices and to improve the information that counties have when they purchase equipment. In addition, it would oversee federal grants to counties for voting equipment, grants to conduct research on voting equipment, and head up an office of standards and certification.

The agency should develop accounting standards for reporting election expenditures and equipment field performance. This needs to be done in order to assess the efficiency of different election systems, and to pinpoint the best places to invest resources for improved performance.

The federal government should provide research funding for the innovation and test-bedding of cutting-edge technologies. One possible way would be to establish a program to field test new technologies in a rigorous and carefully planned way. Without first conducting field pilot tests with real elections on a small scale, the implementation of these technologies is subject to risk.

The federal and state governments should finance and coordinate the upgrade and ongoing maintenance of voter registration databases for counties and states. Voter registration is the largest component of election administration costs, accounting for expenditures of around $350 million a year. Funds should be available for counties on a per capita basis.

PART III
WHAT COULD BE

Paper ballots have served our democracy well. Paper is easy to use. It is easy to check and correct. Paper carries cultural significance. It is satisfying and final to put the ballot in a box. And there have been important improvements in paper ballots: optically scanned paper is more permanent, more secure, and more quickly counted.

But paper has important limitations. In an increasingly large and diverse society, with many languages spoken and many different ballots required, paper is increasingly difficult to administer. Paper is not always as secure and indelible as we would like. It is virtually impossible for a blind person to vote without assistance. And, at the end of the day, voters may still lack confidence that their votes are counted.

Though these limitations apply to all existing technologies. Paper is merely the best of what is.

Our aim is to break through these limitations.

Explode the myth that you cannot see that your vote is counted. Developments in the field of cryptography now make it possible to submit information electronically and check that the information was not altered and was counted.

Explode the myth that electronics must be harder to use and less familiar. We should make equipment that is as easy to use as a paper clip—no instruction required.

Explode the myth that blind people cannot vote without assistance.

Explode the myth that we have to vote at an assigned polling place because of the limitations of the registration system, or that distance voting will be rife with fraud.

Electronics seems like a natural platform in which to tackle these problems. We see a promising future for electronic voting, despite its problems today. In all aspects of our society, we are still feeling our way with computers—making machines easier to use and more secure. As we come to understand computers better, electronic voting promises to break down limitations of our current voting systems. If done right, electronic voting can be friendly and familiar; it can be completely accessible; it can detect and even prevent fraud, and it can assure voters that their votes are counted. Advances in encryption and interface design make new modes of voting possible.

Such developments are possible, but they are not within reach today. They must be the product of a long-term project of our society, a process of continual innovation and improvement in voting technology.

At the same time, we must not lose sight of what voting is about. Voting is not mainly technology.

Voting is a fundamental and special part of our society. Voting should feel like one of the most important acts that we perform, not one of the least important. If we make voting feel like another survey, it will become just that.

Voting is anonymous and private. Privacy of electronic data remains an enormous problem today; we are still figuring out the right way to provide for authentication of voters while protecting their privacy.

Voting is for everyone. We must avoid making equipment that serves as a test of computer literacy, or that makes some votes less likely to be counted. Voting is not a test. It is the way we communicate what we want our government and society to be like and to do.

Voting is administered by dedicated people, most of whom are volunteers, and at the local level.

Voting is a unique, public good. There are no other aspects of our economy or society that resemble voting. No goods or public services are analogous to the vote; no industries offer models for the voting technology industry. Because voting is a public good, there is too little money spent on administering elections and too little investment in research and development.

These social factors constrain what changes are possible, even acceptable.

But, another social aspect to voting compels us to explore fully all means of voting, from paper to the Internet. The United States has long championed democracy throughout the world. The U.S. is a model of how to run a democracy—down to the details of how to administer elections. Many American voting machine companies now sell their equipment worldwide. Other countries may not be able to sustain a challenged election such as that in Florida without damaging the health of their democracy or even without resorting to violence.

Here we present a framework for developing future voting technology, including concrete solutions for testing and standards, for research and development, and for design improvements. We begin by presenting a general framework within which to think about voting technology.

A New Framework for Voting Technology

This section presents a new framework—a reference architecture—for voting that we feel has many attractive features. It is not a machine design, but rather a framework that will stimulate innovation and design. It is potentially the standard architecture for all future voting equipment. The ideas expressed here are subject to improvement and further research.

A Modular Voting Architecture-Overview

We call our framework A Modular Voting Architecture (AMVA). With AMVA votes are recorded on physical items we call "FROGs"—a term chosen specifically to convey no information about the physical form of the recording device. (FROG is not an acronym. A picture of a FROG was chosen as a convenient piece of clip art designed to get the reader's mind off of a specific technology, such as paper, mechanical devices, computer screens, or voice recorders.) A FROG is more than a ballot because it contains information besides the list of votes cast. It also contains information about the official who signed in the voter, about the precinct, and about the form of the ballot. A FROG should be a physical object. It is deposited and becomes part of the audit trail when the voter "casts his or her vote."

A central design choice for this architecture is that we separate the processes of (1) recording a voter's choices on a FROG (capture of preference), and (2) casting the vote using the FROG as input. This separation is familiar to voters using paper ballots or optical scan equipment, but not to those who use typical DRE (Direct Recording Electronic devices) machines.

This separation is crucial. It can help reduce or even eliminate a number of problems with existing voting technology discussed in this report. These problems include security threats posed by complex electronic voting machines, the decline in openness and public control, the need for improved ballot designs, the need for more voter feedback so voters can catch errors, and obstacles to creating independent audit trails, especially on electronic machinery.

The current voting process consists of several distinct steps:

First, voters sign in. Three important things happen when voters sign in. They state who they are. They are asked for identification (authentication). And they are given an initialized and official ballot that contains the offices for which the voter is eligible to vote, based on the voter's residence.

Second, there is a mechanism to capture voters' preferences—for example, a paper ballot or a panel of levers or buttons. The ballot presents choices to the voter and the voter selects the preferred alternatives. We call this *vote generation*.

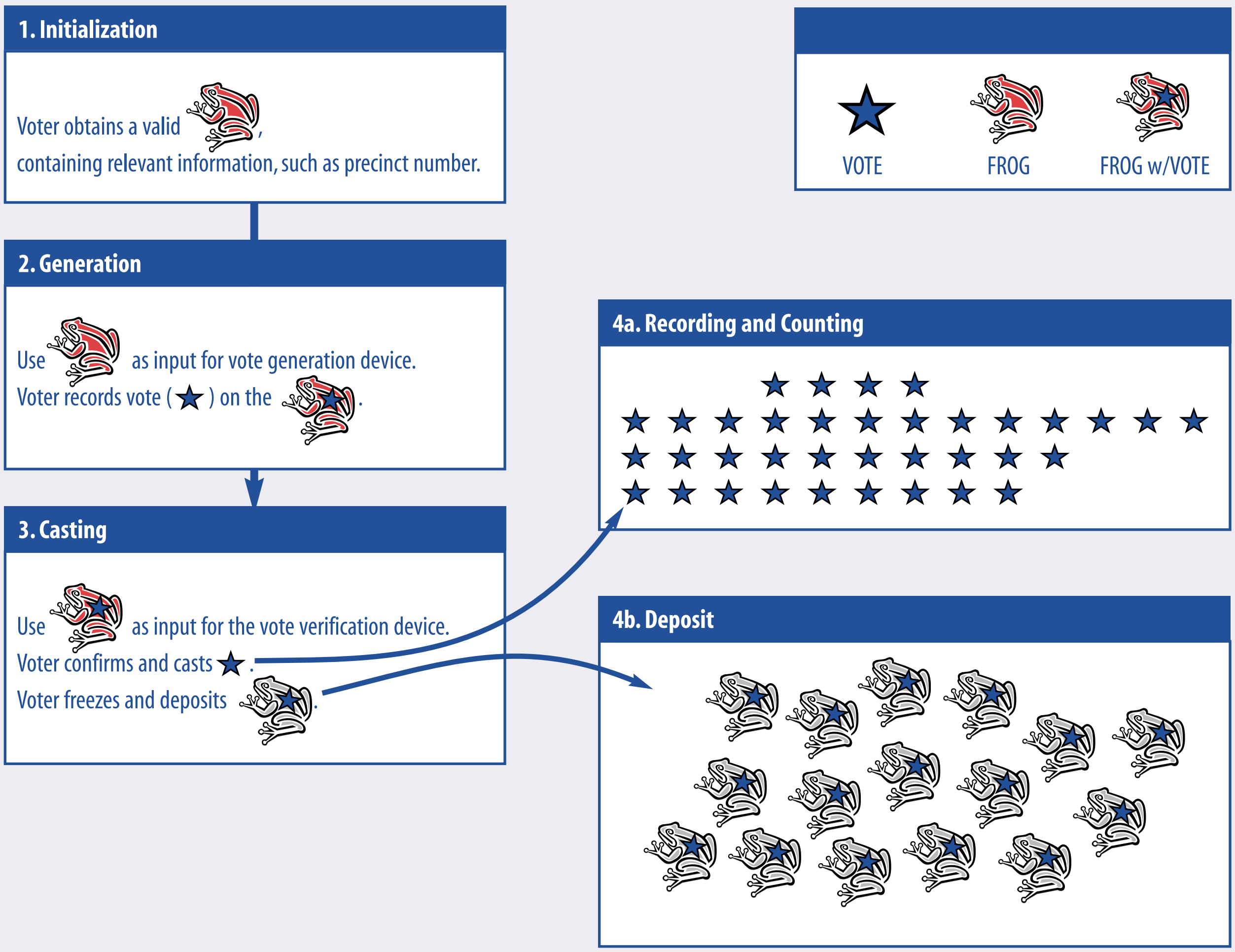
Third, voters *confirm* their selections.

Fourth, votes are cast. This is the critical moment for the security of the ballot. Literally, the voter relinquishes control of the vote, and gives it over to the vote management system.

Fifth, votes are *counted*.

Sixth, votes are *audited*.

A Modular Voting Architecture



Many systems combine steps two, three, and four. We think that both security and ballot design suffer as a consequence. Security suffers because too much is required of a single, increasingly complex machine. Design and innovation suffer because the process for certifying equipment ties the ballot design to the approval of the entire machine. The design of ballots and user interfaces should evolve quickly, without being tied to certification of other parts. At the same time, we need strict standards for security of the casting device and reliability of counting mechanisms. Putting everything in one box significantly limits the ability to have the best ballot design along with high levels of security.

AMVA captures what we consider to be the strengths of both the optical scanning and direct recording electronic systems.

Though optical scan is perhaps today's "dominant voting technology," optical scan has its own problems, including the high cost of printing ballots, the inflexibility of the user interface, and the inaccuracy of the scanners. A good feature of optical scan is that the ballot is directly filled out by the voter and becomes part of the audit trail.

Electronic DRE machines have no printing costs and offer flexible user interfaces. When issues such as rotating candidate positions on the ballot and supporting multiple languages on a ballot are considered, it seems clear that some form of electronic vote entry is likely to become the dominant voting technology at some point. Furthermore, the cost of all forms of electronic equipment continues to drop rapidly; a machine costing $5,000 today might cost $500 in a decade.

However, electronic voting systems are likely to be complex, and complexity is the enemy of security. Such voting systems are likely to be software-based. Ensuring that software is bug-free and secure is notoriously difficult. There may be little that an election official can do beyond accepting a vendor's "trust us" statement, an unacceptable situation.

By separating vote generation from vote casting, and having the voter transport his or her ballot on a FROG from one operation to the other, we achieve several security-related objectives:

First, we have the voter's ballot recorded on a physical object (the FROG) that becomes part of the audit trail once the vote is cast.

Second, the certification of a vote-entry machine may have different standards than that of a vote-casting machine. The vote-entry machine might have lots of graphics-oriented software that is difficult to certify, while the more critical vote-casting machine could be exceptionally simple and easily certifiable.

Third, different manufacturers could produce the vote entry equipment and the vote-casting equipment. (The recording formats and interfaces for FROGs would be standardized and public.) The ability to replace any component with a similar component from a different manufacturer (e.g., for a recount) can assist in reducing the likelihood that a corrupt vendor could bias an election.

We imagine that the election office purchases FROGs in bulk in blank, uninitialized form. Thus, FROGs may be considerably cheaper than printed paper or optical scan ballots. A blank FROG may be a blank piece of paper, a blank memory card costing twenty cents or less, or some other medium with suitable properties. We expect that some form of electronic memory will eventually be the favored representation of a FROG.

Roughly, voting with a FROG works as follows:

First, when a voter arrives at a poll site to vote, he or she identifies him or herself (and authenticates him or herself as necessary) to an election official. The election official takes a blank FROG, "initializes" it, and gives it to the voter. Alternatively, the voter arrives with a FROG.

Second, the voter places his or her FROG in the appropriate "vote-capture" equipment and makes his or her choices, which are recorded on the FROG.

Third, the voter then takes his or her FROG from the vote-capture equipment to the "vote-casting" equipment, and casts his or her vote. His or her FROG is taken hostage and retained as part of the audit trail.

Steps 2 and 3 above should take place privately, so that the voter's vote cannot be observed.

FROG Initialization

Initializing a FROG records on the FROG the identity of the authorizing election official. It also specifies the election and precinct, the corresponding ballot style (that is, which races and candidates are to be presented to the voter), the language to use, and what candidate rotation parameters (if any) are to be used. The identity of the voter is not recorded.

We imagine that the election official has a small device for initializing FROGs as necessary. Each election official may have a unique "key" that must be inserted in order to operate the device, which specifies the official's identity, and which counts the number of FROGs initialized by each official that utilizes that device.

In short, initializing a FROG is similar to having ballots "printed on demand."

Vote Generation

When a voter puts an initialized FROG into the vote entry equipment, it presents the voter with the appropriate ballot choices, and allows the voter to enter his or her selections. The voter is given generous feedback at all stages, and may change his or her vote easily.

In a paper-based system, the FROG may be a scannable paper ballot. Marking the paper ballot is the generation stage.

In an electronic system, the generation stage consists of a session at an electronic panel or with a personal computer (PC). When the voter is satisfied with his or her choices, he or she pushes a "vote-entry finished" button that causes the voter's choices to be recorded on the FROG. The voter removes the FROG so that he or she may place it in the vote-casting equipment.

Vote Casting

The vote-casting equipment has five functions when the voter casts his or her vote. The first is *vote-confirmation*. The FROG is "read" (scanned, electronically read, or whatever is appropriate for this form of FROG), and the voter's choices are displayed to the voter. The voter is asked to confirm that these are indeed his or her choices. If they are not, the voter's FROG is returned to him or her unaltered so that he or she may return to the vote-entry station.

The second function is *vote signing*. The FROG is digitally signed—a cryptographic digital signature of the voter's choices is made by the vote-casting equipment and entered into the FROG. The digital signature key is unique to that vote-signing equipment. It identifies the machine being used and authenticates the vote as having come from that machine. Different machines use different keys. The signature does not identify the voter in any way.

The third function is *vote copying*. The equipment makes an electronic digital copy of the signed vote. This copy will be communicated later on to the recording system.

The fourth function is *vote sealing*. The FROG is "sealed" or frozen so that no further changes may be made to the ballot. With an electronic memory card FROG, a fuse might be blown that disables further writing. With paper sealing might be more difficult to do and might have to be omitted, although laminating the ballot might serve the same purpose.

The fifth function is *FROG capture*. The FROG is taken hostage and saved as part of the audit trail.

Vote Recording

When the election is closed, the vote-casting equipment transmits the electronic copies of the votes, including initialization data and digital signature, to the recording system. Each vote-casting machine displays the number of votes it has signed and transmitted, which is recorded by the election officials. The FROG-initialization machines also display the number of FROGs they have initialized; these numbers are also recorded.

The recording system makes all votes and associated counts publicly available. The votes might, for example, be posted on the Web. Anyone can check the consistency of the counts, verify the digital signatures on the votes, and add up the totals to see who has won each race. We believe that this form of "universal verifiability" greatly enhances security and improves confidence in the result. Universal verifiability of all votes is possible today on all systems except lever machines and several models of DREs. Until recently, Los Angeles County, California created an electronic copy of all ballots cast—the actual image of the punch cards. The ballots could be publicly inspected.

Specific Examples of FROGs

The separation between vote generation and vote casting creates incredible flexibility in the system. FROGs can be created and cast at the polling places as is currently done. FROGs might also be created remotely and then recorded at a recording or polling place.

Paper FROGs

Hand-counted paper ballots most closely approximate the system we envision. When a voter checks in, he or she is provided with a blank, official ballot. The voter goes to a privacy booth and marks the ballot to correspond with his or her preferences (vote generation). The voter can inspect and change the ballot if needed. When the voter is satisfied with the ballot, he or she deposits the paper ballot in the ballot box. Some ballot boxes date, time, and precinct stamp the ballot (vote casting).

This system lacks the authorization by the election official on the ballot itself.

Electronic FROGs in Precincts

When the voter checks in he or she is given a memory card, containing the appropriate information about the ballot, the precinct, and the election administrator. The card is inserted into a slot in a PC. The PC's screen then displays the alternatives, and the voter makes the choices. The machine records the choices on the memory card (vote generation). The voter then takes the memory card to a station with a simple card reading device and screen. This is a completely separate device. The screen displays the choices made by the voter. If the voter wishes to change the ballot, he or she takes the memory card back to the vote generation PC. If the voter wishes to cast the ballot, he or she pushes the "VOTE" button. The memory card is then locked and kept as a physical audit trail. The vote-casting machine records the votes electronically to be counted (vote casting).

Electronic voting today lacks a separate, physical audit trail, and the generation and casting stages are in a single box, which can be both less secure and more expensive.

FROGs from Anywhere

The FROG could also be a paper ballot that is printed from any computer, such as a home PC. The paper shows a list of candidates chosen, the precinct number, and other information such as the vendor's name. The paper FROG also contains a two-dimensional bar code (like in grocery stores) that contains the same information as is printed, but in a format that is readily counted. The FROG is sealed and brought to the polling place, verified, and submitted. The polling place would be equipped with FROGs and with computers for generating votes in case the voter wanted to change the FROG prepared elsewhere.

One interesting aspect of this particular version of AMVA is, if we record the vendor name on the FROG, then vendors could be compensated on a per ballot basis. This would ensure that there was adequate money to stimulate innovation in the development of software.

Discussion

We imagine that each county could purchase the vote-casting equipment. It would consist of a very simple, very inexpensive box.

An independent research laboratory working under the supervision of a panel of security and voting experts would develop the specifications of the vote-counting box. These specifications would be public information, and the box could be built by anyone.

The vote-casting equipment would not be divided into "test" mode and "real" mode. The only difference between a "test" and a "real" election would be the cryptographic keys inserted into the device.

The vote-casting device does not need to understand the races being run and the candidates running for each race. The device merely displays the choices recorded on the FROG, which would be recorded and displayed in a standard text format, such as in the accompanying box. The voter would be able to scroll up and down if necessary to see everything.

We feel that such standardization of electronic formats for ballots will be a major step forward in the evolution of voting systems. It enables the separation of vote entry and vote casting. It provides a path towards remote voting, when and if the security of remote voting systems can be sufficiently ensured. It is both human and machine-readable, and so forms a bridge between these worlds. It enables different vendors to produce interoperable equipment for a voting system.

We repeat our previous concern that systems that do not produce a separate (preferably physical) audit trail are prone to security problems.

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State of Massachusetts, Middlesex County, Precinct 11
Ballot Initialized by Election Official 10
Election Closes November 7, 2004 at 8pm EST
Ballot: MA/Middlesex/1; English; No rotation

You have chosen:
      U.S. President: Mary Morris
      U.S. Vice President: Alice Applebee
      Middlesex Dog Catcher: Sam Smith (write-in)
      Proposition 1 (Casino): FOR
      Proposition 2 (Taxes): AGAINST
      Proposition 3 (Swimming Pool): FOR
```

Similarly, we feel that monolithic systems that try to incorporate everything compromise security.

So, our design places most of the complicated user interface software in the vote-entry system, which is considered to be somewhat less "security-critical." It does need to be reviewed, but it might be acceptable to have such a device contain proprietary code. The vote-entry system might even be run on newly purchased computers or laptops which could then be sold after the election as used equipment.

On the other hand, the security of vote-casting equipment is absolutely critical. This is the last chance for a voter to see his or her vote before it becomes a truly anonymous element in the list of votes cast. The election officials and voters must have strong reason to believe that the vote-casting equipment does not, at the last instant, change the voter's vote just before it is cast.

For this reason, we feel that the vote-casting equipment should be totally "open source"—the software for such a machine should be publicly available. The procedures for ensuring that the equipment actually contains the published software should be public and followed by the election officials. Such machines should be very carefully certified. A county may buy several such machines for each precinct, from different manufacturers.

This division of equipment into two parts may thus solve a problem in the industry: allowing manufacturers to protect some intellectual property (the code for the vote-entry systems) while ensuring that the most security-critical portions are open-source, heavily reviewed, and highly trustworthy.

Note that the vote-casting equipment does exactly the same thing for each election: it merely displays the contents of the FROG, gets the voter's final approval, digitally signs the contents of the FROG, and makes a copy of everything. It does not need to know anything about the particular election being run; the voter is himself taking responsibility for final approval. It does not even have the ability to change a user's vote, if the user does not approve it; that is the function of vote entry. (Of course, we expect that some voters may not bother to read the final confirmation screen carefully; that is their choice. Indeed, we do not expect there are likely to be problems at this stage, although some voters may change their minds at the last instant or they may realize that they forgot to vote in some contest.)

The election officials can take the vote-casting equipment out of the closet, initialize it with the cryptographic signing key it is to use, and then power it on.

Of course, a voter should not be allowed to use the vote-casting equipment unless he or she has been identified as an eligible voter who has not previously voted. Some physical control of the voters at the polling place is necessary. Conceivably one could authenticate the voters at the vote-casting station, but then the issues of ballot-style, language, etc. may not get handled properly, and it seems more awkward to have problems arise at this late stage if there have been problems with the voter's registration from the beginning of the process.

The use of digital signatures is an important and critical part of this design. Anyone who could forge digital signatures could forge votes. The cryptographic digital signature keys need to be carefully managed. A reasonable extension of the basic AMVA design would allow the vote-casting machinery to simultaneously use several signature modules (e.g., each on its own memory card), so that each cast vote is signed by all modules. In addition to the basic signature module supplied by an election official, there may be signature modules supplied by each political party. Requiring several signatures on a vote makes it much harder for a single individual to surreptitiously "borrow" the equipment and forge signed votes. The parties would keep a careful eye on their signature modules, not supplying them until just before the election and retrieving them as soon as the election was over.

Of course, signatures work with paper systems also. The election officer might stamp all of the relevant information on the top of the ballot. When the vote is cast, the ballot is placed in a paper sleeve that only shows the top part. The election administrator would then sign the top of the ballot without observing the votes to certify that everything about the ballot (precinct, etc.) is correct.

The voter's anonymity is nonetheless protected. His or her ballot is identified only by the name (or identification number) of the election official who authorized him or her to vote, and the identity of the vote-casting machine that digitally signed his or her vote. As long as a reasonable number of voters fall into each such bin, anonymity is ensured.

Some care needs to be taken with write-in votes; this issue will be addressed in a longer description of this system. The problem is that a voter might tag his or her vote by his or her choice of a write-in. This, of course, can happen today.

A Process for Innovation

Brazil faces problems with the administration of elections that dwarf those experienced in the 2000 election in the U.S. Low literacy and poor local election management has undercut public confidence in Brazilian elections, and has produced several highly controversial elections. In the 1990s, the Brazilian government responded by creating an engineering consortium devoted to the development of new voting equipment for the country. The consortium consists of engineers and designers employed in two separate activities: equipment development and equipment testing. The development group creates references platforms. Any vendor can bring its machines to be tested and to bid for the national election contract. The degree of testing minimizes the need to set standards.

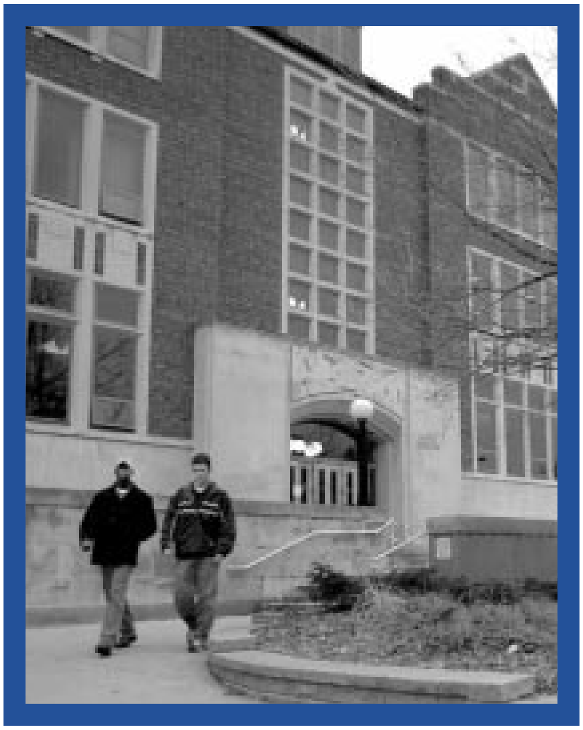
Although the system in Brazil is not flawless, that country has made enormous improvements in its electoral system, thanks in large part to public investment in research into voting systems. We envision a similar investment in the United States.

To our thinking, there are three problems that public investment should tackle.

First, the rate of lost votes attributable to machines in the U.S. is much too high. Our goal is to eliminate lost votes. That means that voters should not be confused or intimidated, ballots should be readable, and touchscreens should be easy to use. The rather high residual vote rate for electronic equipment (2.5 percent for president and 5.5 percent for Senate and governor) is especially alarming. This equipment needs improved ballot designs and user interface designs.

Second, voter registration systems are much too prone to error. Federal funds should target the development of software and database designs suitable for the widely different implementations of voter registration systems. Again the goal should be to reduce the errors in these databases substantially, say from one in five registrations to fewer than one in one hundred.

If we could develop registration systems with errors on the order of one in one hundred and equipment with vote loss on the order of one-quarter of one percent, we could regain almost all of the four to six million lost votes detailed at the beginning of this report.



The third reason for a significant public investment today concerns the future. The United States has evolved over the last century a robust voting system. Actual aberrations due to equipment are statistically rather small, one in fifty, though emotional distress over these aberrations can be significant. Why then does anything need to be done at all? Because the Internet and other new communication and computing technologies are potentially disruptive, their potential should be captured and directed. New technology should not be developed without thorough analysis and design input from those who use equipment—voters and administrators.

Past history has shown that the introduction of new technologies takes place rather slowly, giving them time to evolve true best practices that then become benchmarks. Recent history has shown that electronic and software technologies evolve so rapidly that standards must be developed in parallel. So should it be with voting systems.

We propose a *process* for enabling the voting system to evolve more rapidly than it might otherwise.

AMVA is, we believe, a significant step in the right direction. By separating vote casting from vote generation, we can significantly enhance the security of electronic voting. By separating vote generation from vote casting, we can allow user interfaces and ballot designs to evolve under a separate process designed to maximize ease-of-use and accessibility. But even within this system innovation must occur.

There are three key elements to a process of innovation: laboratory research, field tests, and standards. The discussion that follows focuses on voting equipment. All we say can equally apply to systems and software for voter registration or to systems for Internet voting.

Establish a National Elections Research Lab

The federal government should establish a National Elections Research Lab or program, along the lines of that in Brazil.

The goal of this program is to foster the development of better voting equipment and voting systems. This is not a certification laboratory.

An important enterprise of this lab is to try to "break the systems" and to suggest improvements to machine developers. Knowing how a system can be broken is a key to its evolution. Companies need to know the weaknesses of specific designs so they can improve on those designs. Election officers need to know the weaknesses of equipment so they can watch for problems and administer equipment properly.

With this goal in mind, the program will have four main functions. First, it will develop reference platforms for equipment and software. For example, the program may set up grants for the development of ballot toolboxes, which could be used by administrators to format ballots for all electronic devices, or grants for devices designed to allow blind people to vote without assistance.

Second, the program will work with industry to develop equipment and software for specific purposes. For example, the program might enlist an independent lab to assist a company in optimizing the user interface design on a new electronic voting machine.

Third, the program will test equipment to give feedback to the industry about the performance of its equipment, prior to any certification. The labs associated with the program will conduct human testing of all new voting equipment, as they would be used during a real election. All information from these tests will be conveyed to the firm that developed the equipment. Information from these tests will be publicly available. The lab will make suggested improvements for problems detected during tests.

Fourth, drawing on its experience the lab will consult with the relevant standards setting agencies about appropriate guidelines for equipment, ballot designs, and software.

There are many ways to structure such a program. It may, for example, be a single industrial or university

THE MULTI-PURPOSE VOTING MACHINE

Currently, the business of voting companies is to sell to local governments computers that are devoted exclusively to voting. These computers are used two or three times a year, at most, and then warehoused. Because of the costs of acquiring these voting computers, local governments tend to keep voting equipment for a long time—too long to take advantage of technological innovations.

At the same time, local governments are struggling to maintain the newest computer technology in the public schools.

Perhaps an innovative model of voter technology could address two problems at once—providing the latest technologies to both voting officials and the public schools.

Suppose every four years a county purchased a voting system whose computing power came from personal computers? For instance, a vote generation station could include a box that contained all the innards necessary to be used as a personal computer. The only difference would be that, as delivered to the voting officials, the box would be connected only to peripheral devices that are associated with a voting station, such as a touchscreen to display ballots and a memory card reader/writer (to accept "FROGs"). The box would come loaded only with an operating system and software associated with the function of the system as a vote generation station.

After the election, the computers could be configured to function as conventional school PCs. The vendor would install the necessary connectors, peripherals, operating systems, and software, as part of a comprehensive service contract.

Such a scheme would require funding from state and federal sources. It would require a degree of coordination between school and voting officials.

Still, a model such as this addresses several current difficulties in the voting technology industry. It provides a mechanism to encourage a steady stream of income to the voting equipment industry and smoothes out costs over time. It would encourage the much larger educational software and computer industry to invest in voting technology innovations. It delivers to voting officials a physical and software system that can be certified as "clean" before the election season, yet allowing sharing with other public functions. It provides an attractive alternative use of the computing equipment outside the election season. And it would encourage everyone associated with a large segment of the public sector—the K–12 educational system—to take an active interest in improving voting technology.

laboratory dedicated to voting systems. We envision a program involving several labs, coordinated by a single, public agency, such as the National Institute of Standards and Technology (NIST), and that relies on existing research organizations. There are several key components to a national program.

First, a group of existing laboratories (say three-to-five) will be involved. These are existing organizations, such as industrial labs and universities, that already have expertise and administrative structures for equipment design and testing. Large land grant universities seem like natural places to locate such activities.

Second, a coordinating agency, such as NIST, will develop designs and oversee tests, to ensure quality, fairness and openness.

Third, a coordinating committee, consisting of the labs and the agency, will develop protocols for testing.

Fourth, the program will draw on a wide range of expertise. The labs should draw on their resident expertise in engineering, psychology, design, and testing. They should also involve election administrators and industry in the development of equipment.

Industrial laboratories and universities offer a particularly fruitful ground for this sort of research. They provide an administrative structure for laboratory research at relatively low cost. They can draw on the creativity of researchers working on related subjects. Voting technology, after all, draws on a wide range of expertise—mechanical engineering, political science, operations research, computer science, and cognitive psychology.

Research conducted in independent laboratories is ideal for exploding myths about voting and exploring entirely new ways of voting. An example is research begun by Ted Selker and a team of students at the MIT Media Lab to develop new equipment. They have devised a scheme for converting existing computers to voting machines. That is described in the inset box.

Industrial labs and universities are classic incubation sites. Research laboratories can help to create uniform functional requirements. These can be used to develop new equipment guidelines and standards, and to inform the certification process generally. If uniform function requirements can be found, there is a better chance that new technologies and companies will be created to hasten the evolution of the voting process.

Field Testing Voting Equipment and Standard Ballot Formats

The federal government should establish a program for field testing all voting equipment and standard ballot formats.

Equipment vendors face two big problems getting their equipment from the development stage into the field. First, it is difficult to demonstrate the performance of new equipment; there does not exist a system for testing equipment on real voters. Some vendors now try to do their own pilot or demonstration tests. Second, most counties are skeptical about new machines and reluctant to upgrade. It takes years of "selling" to convince counties that they should use a vendor's machines. As a result, vendors have less incentive to invest in ballot design and user interface equipment.

We are particularly concerned about the future of voting equipment. There is a strong push to upgrade equipment today, from the older systems of punch cards and lever machines, to scanners and existing DREs. Massive purchases today could kill innovation five years out, because counties will have recently purchased equipment. The purchasing of equipment is very lumpy (like other durables), and in five years there may be so little demand for new equipment that innovation withers. We might, then, be left with, perhaps, the best of what is available today. But we will have lost out on the incredible promise of technologies on the threshold of development.

We envision a system of testing that happens each time a vote is cast. Right now, the equipment is tested each time a voter casts a vote. Unfortunately, little use is made of this information, unless there is a sensational election, as in Florida, that provokes a call for new equipment.

How can we exploit the fact that each vote is a test to develop a true testing program, a program of use to machine developers and county officials alike?

We envision three equal partners in the testing program: the federal government, the local governments, and the industry.

First, the federal government should establish innovation grants to local governments. The federal government will pay for pilot projects to test competing technologies of interest to a local community. (This project might be called the Federal Election Equipment Pilot Program, or FEEPP.)

Second, each local government using a FEEPP grant will set aside a number of precincts (depending on county population) and conduct a simple experiment. In each of these pilot program precincts the local government (not the industry) will conduct the election on several different types of equipment. If there are five DRE (Direct Recording Electronic devises) vendors competing, then all five machines will be set up in the precinct. Voters will be randomly assigned to machines. The performance of the machines (residual votes, time it takes to vote, etc.) will be compared. The FEEPP grant will pay for the machines and the set up and administration. The government may contract out to an independent agency (a testing institute or lab) to run the experiments.

Third, vendors will participate only indirectly in the program. The federal government will purchase equipment from the vendors directly, but vendors will not conduct their own trial elections. Vendors will no longer have to bear the cost of such demonstration projects. Participation in the program might be a condition for certification.

The federal agency overseeing the FEEPP will prepare a report on each election's experiments and on each equipment model used. The report will include measures of machine performance and exit surveys of voters. In addition, the agency will post all "ballots" cast so that they can be studied by the industry and election officials to learn about the performance of equipment. An appropriate federal agency to oversee this project may be the NIST.

There are several immediate benefits to such a program.

First, it creates real tests. Real voters are involved, and equipment is used in the precinct. We view this as far superior to the current testing regime.

Second, it gives vendors and election officials a lot of information about equipment. It does not disqualify equipment the way that the existing certification process does. Instead, it gives vendors an incentive to improve on a design.

Third, it is fair. Some vendors run carefully controlled demonstration projects in counties to show that their equipment works. We worry that some of these projects may be "loss leaders," involving considerable investment by the vendors to oversee the election so that nothing goes wrong. Some counties now run equipment "bake offs." Competing vendors are asked to prepare equipment for a demonstration project. Not all vendors compete equally in such competitions; those who have already sold equipment to the county have an edge.

Fourth, it is informative. This program exploits the information that can come from many different counties testing equipment at once. If the typical county has five precincts testing equipment, with four-hundred voters each, and one hundred counties test equipment in an election, then 200,000 votes can be observed. This is enough to measure residual vote rates associated with machines and other measures of performance. It is not feasible to run laboratory experiments of an appropriate magnitude to get the same information. The situation today is even worse than the laboratory experiment design. Counties typically have vendors show their wares at public meetings; no attempt is ever made to measure the performance of the machines.

Fifth, it is not disruptive. The experiment involves a handful of precincts within a county, and the counties are distributed across the states.

Sixth, it gives counties an incentive to innovate. Some counties today are clearly leaders in technology adoption. They get no compensation for being the guinea pigs. The FEEPP gives all counties the incentive to innovate, and spreads the cost of the innovation around. In addition, this program avoids the uncomfortable situation that we are in today regarding federal and state compensation for equipment. In the Florida legislature, representatives from counties that had already purchased optical scanning equipment objected to the legislation proposed by the Governor's Select Task Force on Election Reform, because that legislation offered to pay for an upgrade from punch cards to optical scanning, but it did not compensate counties already using scanners.

Seventh, the proposed program gives vendors the incentive to innovate and protects them from the risks associated with "reluctant counties." Vendors get paid for the equipment used in these tests. They must demonstrate to counties only that their equipment is worthy of consideration in the tests. If the vendor's equipment consistently performs badly, it will not be used on a wide scale and will soon be dropped from the testing program.

Most importantly, we feel that this program will force developers to design equipment with voters and polling place operations in mind. The bottom line is that the equipment must work for the voters, and this program puts that objective in the fore.

Setting Standards

Third, the federal government should create and operate of a National Election Standards Commission to use historically proven methods to develop standards.

Standards commissions, such as those run by the American National Standards Institute, have unparalleled experience in the area of getting often disparate groups to come together and develop a standard that still gives much room for technological innovation and differentiation.

This commission should draw on expertise in industries outside of voting, such as banking, that face similar problems making millions of secure and reliable transactions as well as expertise within the voting area, especially that of local election administrators. The commission should continually review both existing systems and the performance of the standards themselves.

We consider the content of such standards in the next section.

Standards and Testing

What are Voting System Standards and Testing?

Standards are guidelines that voting systems must meet to be acceptable for use in elections, to insure accuracy and security. Voting system standards are documented protocols that set the minimum requirements for the functional, hardware, and software specifications of these systems. Voluntary voting system standards currently exist at the federal level, and over half the states have adopted these standards. Standards also establish a testing regime for voting systems.

The functional specifications of the existing standards cover the basic tasks that a voting system must perform: preparation of the system for an election, the conduct of the election, tabulation and auditing of an election, preservation of records of the election. Security, accuracy, and integrity of the electoral process are the goals for functional specifications.

Hardware specifications cover the basic physical parameters of voting systems. Generally speaking, hardware specifications cover issues like the physical characteristics; the overall design, construction, and maintenance requirements for a voting system; and the ability of the system to withstand various physical stresses associated with use and storage. Goals for hardware specifications include durability, reliability, maintainability, availability, and transportability.

Software specifications cover the components of the voting system that make the hardware work—ranging from ballot construction to storage of ballot data. Software requirements typically specify software design and coding requirements (including both the types of languages that software should be written in and various types of desirable attributes for proper coding practices), documentation of the software, storage requirements for data, and auditability.

Given these functional, hardware, and software standards, there are three levels to the existing testing regime. First, voting systems are submitted for basic qualification testing by independent testing authorities. Qualification testing is the first hurdle that voting systems pass to be certified for use in most states and where voting systems are shown to comply with the voting system standards currently in place, as well as the system's own requirements.

Second, individual states may then require their own certification tests. Last, acceptance tests are then performed by the local election officials, who test systems based on their own requirements to insure that systems meet local regulations, laws, and election practices. Current standards request re-testing of voting systems if modifications are made to hardware or software, but are not clear as to what constitutes a sufficient "modification" to require re-testing.

Where did the Current Voting Systems Standards and Testing Come from?

Until 1990, there were no national standards for voting systems. There was no systematic process of testing, and no guidelines that states or local election officials could use when deciding to purchase and to deploy new voting systems. Voting systems have become increasingly complex and expensive, thus necessitating the development and implementation of standards and testing protocols.

In 1975, a joint effort between the National Bureau of Standards and the General Accounting Office's Office of Federal Elections, produced the first national effort at developing and implementing national standards. This joint effort focused on the accuracy and security of computerized voting systems, and the report that was issued in March 1975 ("Effective Use of Computing Technology in Vote-Tallying") articulated that one of the basic problems with this technology was the lack of evaluative standards and testing procedures for election systems.

This 1975 report led Congress to task the Federal Election Commission (the agency that the General Accounting Office's Office of Federal Elections turned into) and the National Institute of Standards and Technology (NIST) to produce a study about the feasibility of developing voluntary standards and testing procedures for voting systems. These agencies produced their report in 1984, titled "Voting System Standards: A Report on the Feasibility of Developing Voluntary Standards for Voting Equipment." Based on the recommendations in this 1984 report, the Federal Election Commission immediately began to devise national standards and testing procedures.

In 1990, the Federal Election Commission published their standards and testing protocols for punch card, optical scan, and DRE (Direct Recording Electronic) voting systems, in a report titled "Performance and Test Standards for Punchcard, Marksense, and Direct Recording Electronic Voting Systems." These standards and testing procedures have become the basis for state certification of voting systems in most states. The current process, established by the National Association of State Election Directors (NASED), seeks to facilitate the evaluation of voting systems by independent testing authorities. Wyle Laboratories is the one independent testing authority certified by NASED to test voting system hardware. NASED has a voting system committee that oversees the voting systems testing process. Currently the Federal Election Commission standards and testing procedures are being rewritten and a revision is expected in January 2002.

Suggestion to Improve Current Standards and Testing

The existing standards process is a step in the right direction, but it does not cover many of the problems that we have detected. First, the standards do not apply to the way voters use machines or the way machines are actually set up in the precincts. Second, the standards tie the electronic user interface to the components for casting the vote, because focus is on a single box. This slows down the development of the user interface, and puts the onus on NASED to certify a very complicated piece of machinery. Third, important things are not reviewed currently, including ballot and user interface designs, auditability, and accessibility.

Within the existing standards framework we recommend several immediate changes.

Include Real Voters in Testing Process

The existing testing protocols all focus on hardware and software testing in a laboratory environment. The testing is of votes that machines generate, not of votes generated by people. For example, a machine scores the punch cards or the optically scanned ballot. Then, the counting device processes the machine scored cards. Similarly, touchscreen computers are run in a "test" mode in which the machine generates the choices. This practice tests the counting device under ideal circumstances; it is a good first level performance test.

Hardware and software must be tested on samples of human subjects—likely voters—in scientifically controlled settings. For example, people may not darken optically scan ballots as cleanly as machines do, and as a result the performance of the counter will be significantly worse than the test performance. We recommend human testing and reporting of the human test results alongside the machine test mode.

Test Equipment as It Is Set Up and Used at the Polling Place

At one public demonstration, we witnessed a set of daisy chained DRE machines fail because of lose cables connecting the equipment to a central server. When someone shook the cables all of the counters on the machines reset to zero.

Events such as this one should never happen, and equipment susceptible to such problems should never be certified. The problem is that the equipment is not tested as it is set up in the polling place.

Require that All Non-interface Software Be Open Source

All non-interface software must be open source, for the security reasons discussed earlier.

Re-test Systems after Field Use

Systems must be re-evaluated after use in the field. How does a typical voting device from a vendor's system perform after a certain number of uses by voters or local election officials? Is there a degradation in performance, and is it acceptable? We do not know, for example, how long electronic equipment lasts.

Perform Random System Audits

End-users of voting systems must randomly select some set of units from their voting system to be disassembled and closely inspected after each election. This machine audit would be conducted to insure the integrity of the voting system.

These are changes that can be made within the existing framework. Over the long-run, we believe that a new process for developing standards is needed.

Separate the Certification Process for Ease of Use and for Security

Testing of a single box that is used to generate votes and cast them is suboptimal. Desired changes in the user interface may be slowed by the prospect of subjecting the entire machine to certification again.

Uncoupling these two standards steps will speed up the certification process. It will allow user interfaces to evolve quickly. It will allow developers to maximize the security surrounding the casting and counting of votes.

Separating the certification for different aspects of voting will also encourage interoperable equipment, with one vendor providing certified user interfaces and another vendor providing certified vote-casting devices.

Develop New Testing Protocols and Guidelines for Ease of Use of Ballots and User Interfaces

Clear and consistent guidelines for ballot design and user interface design are needed.

Interface designs must be tested on human subjects in scientifically controlled settings.

In general, we think guidelines are more appropriate than standard specifications for user interface and ballot design. Graphical design and ease-of-use are complicated areas. Guidelines would help manufacturers and counties. In the case of A Modular Voting Architecture (AMVA) system, the standardized ballot interface is that seen by the voter when he or she confirms and casts the vote. The clarity of that interface must be tested and then standardized.

Develop a Standard Process for Review of Ballots and User Interfaces

We feel the review of ballots and user interfaces could be done most effectively at the state level. We recommend the following criteria:

First, use clear and simple language. For example, "Write-In" confuses some voters. "Someone Else" is preferable.

Second, make actions clearly distinguishable. One problem with lever machines is that it is difficult to distinguish the offices because there are no breaks between the levers.

Third, map actions to choices clearly. The problem with the butterfly ballot was the confusing mapping of actions to choices.

Fourth, make it easy and obvious how to change your choice. Some DREs are difficult to use because it is unclear how to undo what you have chosen.

Fifth, clearly indicate what voters have done.

In addition, every effort should be made to make all precincts accessible. This may mean developing specific equipment designed to make it easy for blind people to vote. It might also mean developing a secure absentee voting process for people with disabilities.

Develop Hardware and Software Specifications for Vote Casting-Devices

Specification of the vote-casting components will allow for greater security. All software used for casting and counting votes must be open source.

Create a New Standard for Redundant Recordings

All voting systems should implement multiple technological means of recording votes. For example, DRE/touchscreen systems should also produce optical scan ballots. This recount redundancy insures that independent audit trails exist post-election, and it helps insure that if fraud or errors are detected in one technology there exists an independent way to count the vote without running another election.

Develop Standards for Voter Educational Materials

The materials used to instruct voters how to vote should be tested for clarity and effectiveness. These tests should be used to develop standard instructional materials.

Create a National Elections Standards Commission

The federal government should create a National Elections Standards Commission along the lines of those run by the American National Standards Institute to use historically proven methods to develop new standards for voting equipment.

Standards and testing procedures must be flexible and adaptable. The standards and testing process should not slow or stifle technological innovation. Standards commissions, such as those run by the American National Standards Institute, have unparalleled experience in the area of getting often disparate groups to come together and develop a standard that still gives much room for technological innovation and differentiation.

Information and Openness

Open information helps to ensure the integrity of the electoral system. Registration rolls are public documents, subject to public scrutiny. Voters present themselves to the check-in desk at a precinct by announcing their name publicly to be recorded by official poll workers and party "poll watchers." At the end of the day the precinct is secured and those present, including rank-and-file voters if they wish, witness the counting of the ballots. Preliminary counts are reported to local government offices where they are reported almost immediately to the public and the press. Precinct tallies are kept by local governments and available for inspection by citizens.

When viewed from the most local of perspectives, the precinct, information concerning the conduct of elections is exceptionally open. Yet as we have studied the electoral system from a national perspective, we have also experienced how short a distance information about the local conduct of elections travels. Precinct tallies are filed in boxes, accessible only to people who can physically travel to court houses and town halls. Information about machine malfunctions is trapped in internal memos and the local election office oral tradition. Reports of administrative innovations in the conduct of elections are contained in courthouse chatter.

The conduct of elections would be significantly improved in the United States if the amount of locally produced information about election administration were more broadly and systematically collected and reported to the public, to the press, and to election administrators nationwide. Broad dissemination to the public would help reassure voters about the integrity of the system and help expose those areas where the system has broken down or could be improved. A broader dissemination to the national election administration community would help them gather together the best practices of their colleagues. Information about equipment acquisitions and performance will lead to better informed decision making about equipment turnover and replacement. Better information of this kind will give counties, especially small counties, more equal footing in bargaining with vendors about equipment and services.

What information needs to be more widely available? The following information is generated—or in principle could be generated—at the local level in the regular conduct of elections. All of it is valuable in assessing the performance of the system.

Vote outcomes should be reported by individual precincts, for all contests. Total votes cast by all methods should be reported. Also, precincts should produce detailed reports of the votes cast by method—absentee, early, and in precinct.

Each precinct should report the total number of voters who cast a ballot in each precinct, not simply the number of people who cast a legal ballot for individual offices. Blank ballots, overvoted ballots, and otherwise spoiled ballots should be reported as separate categories for each contest. These totals should be balanced at the end of the day, at the precinct, county, and state levels. For each precinct and for each race the total number of voters who cast a ballot should equal the valid ballots plus the overvoted ballots, plus the otherwise spoiled ballots for that race. These "balance sheets" should be reported separately for onsite, early, and absentee categories. They should also report the number of people who were turned away from each precinct, and the reasons why. Jurisdictions that rely on provisional ballots should report the number of such ballots that were eventually allowed and the reasons why provisional ballots were rejected.

Following each election, local governments should report the cost of conducting the election, accounting for costs associated with different modes of conducting the election (in precincts, absentee, etc.). Counties should also report annual election administration costs, broken down by several categories—voter registration, equipment purchases and payments, equipment storage and service, polling place operations, and administrative overhead. Annual state-level expenditures by the secretary-of-state offices at the state level should be reported separately from the county expenditures.

Local officials should report the types of machines used in their jurisdiction to record and count ballots. This should include the vendor, machine vintage, and machine brand name.

Local officials should report performance-related issues that impede the smooth administration of elections, such as levers that jam on lever machines or optical sensors that malfunction on optical scan devices. They should also report the results of election audits they conduct, to ensure the proper functioning of the equipment.

As local governments enter into contracts with vendors to purchase or lease election equipment, requests for proposals (RFPs) and actual contracts should be reported.

Local governments currently vary significantly in the degree to which this information is made available to the public. Even such basic information as voter turnout is not uniformly available nationwide. In 2000, for instance, a dozen states did not require their local governments to report the number of voters who cast a ballot on Election Day, making it impossible to assess how many ballots went uncounted in those states. The other information listed above is generally available, for the asking. But, to gain a nationwide perspective on the performance of the electoral system, it is oftentimes necessary to ask the same question more than 3,000 times.

Therefore, the states and the federal government have important roles to play in the collection and dissemination of information about the performance of the electoral system. Because the conduct of elections is mostly a state responsibility, states can act now to improve the availability of election information from their local governments. This is the most critical—but also easy to achieve— function in the realm of reporting vote returns and machine information.

The federal government has an important role to play in the reporting and disseminating of information about the election system. The federal government can, first, help to develop uniform reporting standards, which would benefit state and local governments seeking to achieve uniformity themselves, as well as benefit national voting equipment vendors, who are in need of consistent information in order to develop and improve their products. Second, the federal

government can help establish a more efficient market in information about the performance of election equipment and the fiscal administration of elections, by helping to establish a national clearinghouse of information about machine performance and vendor contracting.

Developing reporting standards and a clearinghouse for information about voting systems is a task for a federal agency dedicated to the efficient conduct of national elections. For many years, the Office of Election Administration within the Federal Election Commission has performed a similar task, but on a more limited scale than is necessary to inform counties and the public about what works and what does not. The federal government should expand the Office of Election Administration or develop a separate agency dedicated to performing the function of collecting and disseminating information about election administration.

CONCLUSION

We can cut the number of lost votes in half by 2004 with two reforms.

First, replace punch cards, lever machines, and older full-faced DREs (Direct Recording Electronic devices) with optical scanning systems that involve counting ballots in precincts, or with any electronic technology proven in field tests. We estimate that this would save approximately 1.5 million votes.

Second, make county-wide (or possibly state-wide) voter registration data available at polling places, in electronic or hard copy. Provide a fall-back system, such as provisional ballots, to allow people to vote if registration problems cannot be resolved at the polling place. More accurate and complete registration information combined with a fail-safe procedure could cut the number of registration problems by at least two-thirds, approximately two million votes.

We must spend what is needed to implement these changes. Equipment upgrades would cost about $2 per voter per year. It is harder to set a price tag on voter registration reforms. We estimate that it would cost about $2 per voter to lease lap tops for election day equipped with voter registration lists and to provide for someone to operate that equipment. Total costs of these improvements come to $4 per voter per year, or $400 million per year. That is almost a fifty percent increase in election administration expenditures in the United States.

We view the price of these reforms—$4 per voter per year—as insurance: insurance against problematic elections in the future; insurance that each vote will be counted. It cuts the risk in half of a vote being lost.

Real, long-term reform is not just about choosing among existing technologies and systems. It is about capturing the great potential coming out of the current computing and communication revolution and harnessing that potential to break fundamental myths about voting.

Some day each voter will be able to verify that his or her vote was counted without compromising the security of the ballot.

Some day voting equipment will be familiar and easy, rather than unique and cumbersome.

Some day voting will be very convenient for voters and administrators—long lines and chaotic Election Day management problems will be history.

Some day the awkward problems of voter registration will be solved, and election officials can authenticate voters without a separate pre-registration.

Today, many creative people are working to develop new voting technologies. Many new machine designs are in development and many new firms are working on the problems highlighted by the 2000 election. In their promise, there are also risks. There is the real risk that machines might have many desirable features, but not really improve on what is. There is the real risk that Internet voting is compromised by a denial of service attack, invalidating elections throughout a state or the nation. But, we must not be deterred by these risks, because there is an even greater risk that inertia might leave us in our current dilemma. We should not tolerate things as they are; the inadequacies of our voting system threaten our democracy.

A system for design and evaluation will allow the U.S. to harness the energy from the explosion of new ideas for how we can vote.

We have developed a new framework for voting—a reference architecture—that will allow us to ensure high levels of security and stimulate the evolution of familiar and friendly ballots.

We envision a research program aimed at developing ballot designs and equipment that are easy to use and accessible to all.

We call for a process of continual evaluation of equipment, both in the laboratory and in the field, to allow for true assessments of competing technologies, but also for improvements in these technologies.

And, we see the need for the federal government to collect and disseminate information about voting equipment, systems, and contracts, to empower counties and states to make the best choices possible.

Any component of this process would likely stimulate significant improvements for the future of voting. Taken as a whole, it is a process for perfecting elections and for restoring confidence in elections in the United States.

In many ways the U.S. has been working toward such a process, through the efforts and the activities of many election officials and firms. Leadership from the Congress and the President can make this vision a reality.

APPENDIX

Suggested Readings

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Estimating Lost Votes

Votes are lost for two different reasons. First, some votes are not counted because of voter mistakes or confusion casting ballots or because of equipment unreliability or errors. Second, some voters want to vote but are denied a ballot because of a failure in the system. For example, the voter's registration is out of date or the voter cannot obtain an absentee ballot.

From election returns we can estimate how much loss is due to equipment problems. This is discussed at length in the equipment section of the report. Depending on the assumptions made about the fraction of uncounted votes for president, we estimate that approximately 1.5 million votes for president were intended to be cast but not counted in November 2000 (see Part I, "Lost Votes"). In addition, approximately 2.5 million votes were lost in races for Senate or governor over the last complete election cycle.

Vote loss due to accessibility is much harder to estimate because we must rely on survey data. Researchers do not always write survey questions right, and people are notoriously bad at answering surveys. The best available data come from the 2000 Current Population Survey's (CPS) Voter Supplement File. Respondents who said they did not vote in the November 2000 elections were asked: "What was the main reason [you/name] did not vote?" Respondents were given eleven different reasons, and the responses are provided for both 1996 and 2000 in the accompanying table "Why Registered Voters Say They Don't Vote."

There were approximately 40 million registered voters who did not participate in the November 2000 elections. Over 7 percent of the CPS survey respondents said they did not vote because of "Registration problems (i.e., didn't receive absentee ballot, not registered in current location)." Just under 3 percent report "long lines and short hours" as an obstacle. In addition, 11 percent cite "other reasons," some of which might be related to registration.

There are three scenarios for these data.

First, we could take them at face value, which we do in the text. That is, registered voters who could not vote because of registration problems went to the polls but could not vote because of a mix up. Also, registered voters who said the lines were too long would have voted if the lines were shorter. That yields an estimate of 3 million lost votes due to registration problems and 1 million lost votes due to lines.

Second, the registration numbers could be higher. The registration question lists a couple of reasons for registration problems. It is well known in survey research that such "prompting" affects the way that people answer questions. Because the text of the question is not exactly right, the respondent may have cited "other reasons" even though the problem really lies in the registration system. Nearly 11 percent citing other reasons might include registration problems. A more liberal reading of these data, then, would put the numbers with registration problems higher than 3 million.

Third, the real numbers encountering registration problems could be lower. We do not know exactly how many of the 7.4 percent who stated that they had registration problems actually had problems and how many are blaming the system. Our subjective belief is that a conservative estimate of the number of lost votes due to registration problems is 1.5 million voters.

This guess is based on the assumption that half of the 7.4 percent did not participate because they were not registered in their current location. Similar inflation of the responses might occur with the category "lines" because some people might just be complaining about the system.

Rather than relying only on the 2000 CPS responses, we have also looked at responses to the same question in other recent years (1996, 1998). Estimates from those years imply somewhat smaller numbers of lost votes due to registration and polling place problems, about 50% less than the 2000 estimates: 1.5 million due to registration, and 480,000 due to lines and hours (in addition to the 1.5 million lost due to ballot problems). Nevertheless, adding up these three numbers still yields a very large number of lost votes: 3.5 million. Of these, we expect that half could be recovered with changes in voter registration and polling place operations, and equipment improvements.

These calculations suggest that the number of lost presidential votes in 2000 is between 3.5 and 5.5 million, but possibly higher, depending on the reliability of the CPS data. We round these figures up to 4 to 6 million, because we are being conservative about the baseline number of registered non-voters and because these figures do not include other problems, for which we do not have an accounting. In addition, we estimate that equipment problems account for another 2.5 million votes in Senate and gubernatorial elections over the last cycle for those offices.

USAGE OF VOTING EQUIPMENT IN THE 1980 AND 2000 ELECTIONS

		Percent of Counties Using Technology		Percent of 2000 Population Covered by Technology	
		1980	2000	1980	2000
Paper Ballots		40.4	12.5	9.8	1.3
Lever Machines		36.4	14.7	43.9	17.8
Punch Card	"VotoMatic"	17.0	17.5	30.0	30.9
	"DataVote"	2.1	1.7	2.7	3.5
Optically scanned		0.8	40.2	9.8	27.5
Electronic (DRE)		0.2	8.9	2.3	10.7
Mixed		3.0	4.4	10.4	8.1

VOTER REGISTRATION IN THE UNITED STATES

	1992	1994	1996	1998
Voting Age Population (VAP)				
Total VAP (millions)	189.5	193.7	196.5	200.9
Voter Registration				
Total active registrants (millions)	—	129.4	143.0	141.0
Active registrations as pct. of VAP	—	66.8%	72.8%	70.2%
Total inactive registrants (millions)	—	1.6	7.1	14.6
Total registrations (millions)	133.8	131.0	149.8	156.7
Registrations as pct. of VAP	70.6%	67.6%	76.3%	78.0%
New Voter Registration				
Total applications[a] (millions)	—	—	41.5	35.4
Total new registrants (millions)	—	—	27.5	17.6
Deletions from Voter Lists				
Deleted from active list (million)			5.1	5.1
Deleted from inactive list (million)			0.8	0.7
Total deletions (million)			8.7	9.1

Source: Federal Election Commission, from state reports.
[a]Includes changes in registration, in addition to new registrants.

RESIDUAL VOTE BY STATE, 1996 AND 2000

	1996	2000
Alaska	1.5	0.8
Arizona	1.9	1.8
California	2.4	1.6
Colorado	2.6	—
Connecticut	1.3	1.0
District of Columbia	1.8	—
Florida	2.5	2.9
Georgia	3.2	3.5
Hawaii	2.7	0.9
Idaho	3.2	2.9
Illinois	2.4	3.9
Indiana	2.7	2.1
Iowa	1.4	0.9
Kansas	1.4	1.9
Kentucky	2.2	1.5
Louisiana	1.1	0.6
Maryland	0.7	0.5
Massachusetts	1.7	1.1
Michigan	1.6	1.1
Minnesota	0.8	—
Montana	2.4	1.8
Nebraska	1.4	1.4
Nevada	0.7	1.3
New Hampshire	2.9	1.7
New Jersey	0.9	1.0
New Mexico	3.3	2.8
New York	1.9	2.0
North Carolina	—	3.3
North Dakota	2.0	1.4
Ohio	2.2	1.9
Oregon	1.5	1.6
Rhode Island	—	0.8
South Carolina	4.3	3.4
South Dakota	1.7	1.8
Utah	3.7	1.8
Vermont	1.2	1.1
Virginia	—	1.8
Washington	1.7	1.3
West Virginia	2.6	—
Wyoming	2.0	3.6

Note: Reported data from the following states was insufficient to calculate residual vote: Alabama, Arkansas, Colorado (2000), Delaware, D.C. (2000), Maine, Minnesota (2000), Mississippi, Missouri, North Carolina (1996), Oklahoma, Pennsylvania, Rhode Island (1996), Tennessee, Texas, Virginia (1996), West Virginia (2000), and Wisconsin.

Sources: Election Data Services (1996); Caltech/MIT Voting Technology Project, from state election sources (2000).

RESIDUAL VOTE OF 40 LARGEST COUNTIES IN THE UNITED STATES

Rank	State	County	Major city	Residual vote (%)
1	CA	Los Angeles	Los Angeles	2.7
2	IL	Cook	Chicago	6.2
3	TX	Harris	Houston	2.2
4	CA	San Diego	San Diego	2.0
5	CA	Orange	Los Angeles suburb	0.8
6	AZ	Maricopa	Phoenix	1.7
7	NY	Kings	NYC (Brooklyn)	4.0
8	FL	Miami-Dade	Miami	4.4
9	NY	Queens	NYC (Queens)	3.5
10	MI	Wayne	Detroit	1.3
11	TX	Dallas	Dallas	0.4
12	WA	King	Seattle	0.7
13	NY	New York	NYC (Manhattan)	3.2
14	CA	Santa Clara	San Jose	1.8
15	FL	Broward	Ft. Lauderdale	2.5
16	PA	Philadelphia	Philadelphia	—[a]
17	MA	Middlesex	Boston suburb	1.0
18	CA	San Bernardino	Los Angeles suburb	2.0
19	OH	Cuyahoga	Cleveland	2.7
20	PA	Allegheny	Pittsburgh	—[a]
21	NY	Nassau	NYC suburb	1.2
22	NY	Suffolk	NYC suburb	0.7
23	CA	Riverside	Los Angeles suburb	0.9
24	CA	Alameda	Oakland	1.5
25	TX	Tarrant	Ft. Worth	1.6
26	TX	Bexar	San Antonio	0.9
27	MI	Oakland	Detroit suburb	0.7
28	NY	Bronx	NYC (Bronx)	4.7
29	MN	Hennepin	Minneapolis	0.3
30	NV	Clark	Las Vegas	1.1
31	CA	Sacramento	Sacramento	1.7
32	FL	Palm Beach	West Palm Beach	6.4
33	OH	Franklin	Columbus	0.8
34	MO	St. Louis	St. Louis	0.3
35	NY	Erie	Buffalo	1.7
36	FL	Pinellas	St. Petersburg	2.1
37	NY	Westchester	NYC suburb	1.9
38	VA	Fairfax	Washington suburb	0.9
39	WI	Milwaukee (City)	Milwaukee	0.3
40	NJ	Bergen	NYC suburb	0.7

Source: CalTech/MIT Voting Technology Project, from state election sources (2000).
[a]Total turnout not reported by the county.

WHY REGISTERED VOTERS SAY THEY DON'T VOTE

	1996	2000
Illness or disability	4.5%	16.0%
Out of town or away from home	11.5%	11.1%
Forgot to vote	4.5%	4.3%
Not interested, felt my vote wouldn't make a difference	17.0%	13.2%
Too busy, conflicting work or school schedule	22.1%	22.6%
Transportation problems	4.5%	2.6%
Didn't like candidates or campaign issues	13.4%	8.3%
Registration problems	—[a]	7.4%
Bad weather conditions	—[a]	0.7%
Inconvenient polling place or hours or lines too long	1.2%	2.8%
Other	10.6%	11.0%

Source: U.S. Census Bureau, Current Population Survey, Voting and Registration Supplement.
[a]Response option not included in 1996 survey.

VOTER REGISTRATION SYSTEMS, BY STATE

State	Local voter registration systems	State periodically collects local voter registries	State has some local registries online	State has all local registries online
Alabama			Yes	
Alaska				Yes
Arizona		Yes		
Arkansas				Yes
California		Yes	Implementing	
Colorado			Yes	Nearing passage
Connecticut				Implementing
Delaware				Yes
D.C.				Yes
Florida		Implementing		Nearing passage
Georgia				Implementing
Hawaii				Yes
Idaho	Yes			
Illinois		Yes		
Indiana		Yes		Nearing passage
Iowa			Yes	
Kansas		Yes		
Kentucky				Yes
Louisiana				Yes
Maine	Yes			
Maryland			Yes	Implementing
Massachusetts				Implementing
Michigan				Yes
Minnesota				Yes
Mississippi	Yes			
Missouri			Yes	
Montana	Yes			
Nebraska			Implementing	
Nevada	Yes			
New Hampshire	Yes			
New Jersey		Yes		
New Mexico		Yes		
New York	Yes			
North Carolina				Implementing
North Dakota		No voter registration		
Ohio		Yes		
Oklahoma				Yes
Oregon	Yes			
Pennsylvania	Yes			
Rhode Island	Yes			
South Carolina				Yes
South Dakota	Yes			
Tennessee		Implementing	Planned	
Texas			Yes	
Utah			Yes	
Vermont	Yes			
Virginia				Yes
Washington	Yes			
West Virginia		Implementing		
Wisconsin	Yes			
Wyoming			Implementing	
United States	14 current	8 current 3 implementing	7 current 3 implementing 1 planned	12 current 6 implementing 3 nearing passage

Source: "Statewide Voter Registration Systems," Election Data Services Inc., 31 May 1997, updated from Mary M. Janicki, "Statewide Voter Registration Systems," Connecticut Office of Legislative Research, 17 January 2001, and "2001 Legislative Scan on Election Reform," Center for Policy Alternatives, 9 May 2001. Compiled by John Mark Hansen for the National Commission on Election Reform.

NUMERIC IDENTIFIERS FOR VOTER REGISTRATION, BY STATE

	Request			Require	
State	Full SS#	Last 4 digits of SS#	Driver's License number	Full SS#	Last4 digits of SS#
Alabama	•				
Alaska	•				
Arizona		•			
Arkansas	•				
California			•		
Colorado	•				
Connecticut					
Delaware	•				
D.C.	•				
Florida					•
Georgia				•	
Hawaii				•	
Idaho	•				
Illinois	•				•
Indiana	•				
Iowa	•				
Kansas	•				
Kentucky				•	
Louisiana	•				
Maine					
Maryland	•				
Massachusetts					
Michigan			•		
Minnesota					
Mississippi	•				
Missouri					•
Montana					
Nebraska					
Nevada				•[a]	
New Hampshire					
New Jersey					
New Mexico				•	
New York					
North Carolina			•		
North Dakota	No voter registration				
Ohio	•				
Oklahoma					•
Oregon					
Pennsylvania					
Rhode Island					
South Carolina				•	
South Dakota	•				
Tennessee				•	
Texas	•		•		
Utah		•	•		
Vermont					
Virginia				•	
Washington					
West Virginia		•			
Wisconsin					
Wyoming					
United States	16 states + DC	3 states	5 states	8 states	4 states

[a] Nevada allows use of a driver's license number or state-issued voter ID number as an alternative.
Source: Federal Election Commission, National Voter Mail In Registration Instructions. Compiled by John Mark Hansen for the National Commission on Election Reform.

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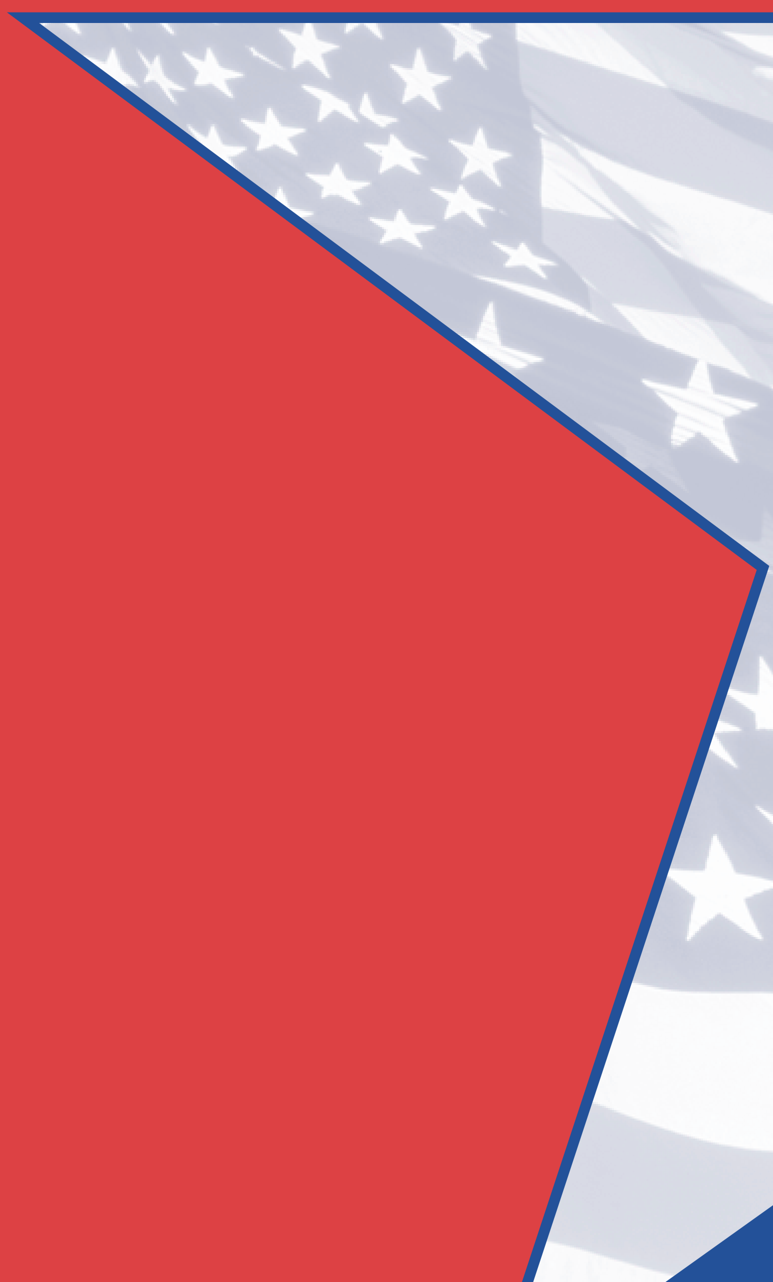

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