IN SEARCH OF SECURE AND ACCURATE ELECTRONIC VOTING SOLUTIONS -A MANUFACTURER'S PERSPECTIVE

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Predictable collective failures of electronic voting solutions that are not adequately designed and engineered!

With recent frustration over the string of failures of Direct Recording Electronic (DRE) voting systems all over the nation, it is not surprising to find that the public sentiment is to avoid electronic voting at all costs.

Paper ballot systems are suddenly being viewed as a panacea to the vulnerability of electronic voting machines to tampering and errors. One may not know that paper ballots and DRE ballots are deciphered by similar software and have demonstrated similar security vulnerabilities when they are designed and engineered without rigorous guidelines. A more reasonable approach for choosing a voting system would be based on avoiding systems that have been proven to have serious design and engineering flaws, and gravitate towards those that are well-engineered and proven as secure, easy-to-use, low cost-of-ownership and reasonably priced. This choice is unavoidably a mix of voting solutions based on electronic systems such as DRE systems and ballot-marking devices (BMD) that provide both accessibility to voters with disabilities, as well as some form of paper ballot.

Not unlike most computer experts and concerned citizens calling for a more secure voting solution, AVANTE has predicted and expected that this day will come. The day when the public will begin to worry about the accuracy and trustworthiness of elections held with DRE systems, even those with a voter-verifiable paper ballot (VVPB) or voter verified paper audit trail (VVPAT). Being the first company to provide DRE systems with a VVPB in March 2001, we illustrated in detail how and why a VVPB (we will use VVPB interchangeably with VVPAT in this paper) should be incorporated into currently existing electronic voting machines in several white papers posted to the web in 2003[1]. In these 2003 white papers, AVANTE outlined all the potential technical issues and proper solutions relating to a VVPB.

Now in the midst of the primary elections of 2006, this day has finally arrived. Our worst fears and predictions made in 2003 have been realized[2] [3] [4] [5]. The failures of the vendors with inadequate design and engineering have inadvertently succeeded in creating a perception that VVPB has problems of its own. In short, the inevitable outcome of the fact that the DRE with or without VVPB can, if inadequately designed and engineered, fail!

In this white paper, we hope to point out to the public that there are properly designed and diligently engineered DRE with VVPB solutions that are low in costs of ownership, secured and do not induce any voter errors. Even more importantly, they have been used and proven.

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[1] "A Manufacturer's View Point On the Voter Verifiable Paper Record and Audit Trail" http://www.vote-trakker.com/White%20Papers/A%20Manufacturer%27s%20View%20Point%20On%20the%20voter%20verifiable%20paper%20record%20FINAL.pdf

[2] DRE Analysis for May 2006 Primary – Cuyahoga County, Ohio http://bocc.cuyahogacounty.us/GSC/pdf/esi_cuyahoga_final.pdf
Misinformation and Missed Opportunities http://www.votetrustusa.org/index.php?option=com_content&task=view&id=1833&Itemid=26
Major Problems At Polls Feared http://www.washingtonpost.com/wp-dyn/content/article/2006/09/16/AR2006091600885_pf.html

[3] The Big Election Beta Test http://news.com.com/The+big+election+beta+test/2100-1028_3-5433101.html

[4] NOW Transcript – September 6, 2006 http://www.pbs.org/now/transcript/236.html

[5] CNN's Lou Dobbs: 'Flawed elections? We're talking about a disaster here' http://www.bradblog.com/?p=3580#more-3580
ES&S MELTDOWN: Tabulators Fail in Arkansas on Election Day, SoS Announces Inquiry http://www.bradblog.com/?p=2867

These alternatives to the inadequately designed and engineered solutions made by the more established traditional vendors are available and used today. These systems of DRE with VVPB and paper ballot and deciphering solution that prevent paper ballot stuffing are not conceptual or academic that are years away. They are solid solutions that have been proven in US elections.

How should a secure and accurate DRE work?

Table 1 is a summary of the potential problems and solutions for DRE voting systems that have been discussed in detailed in the 2003 AVANTE white papers. The solutions have been available since 2001 and the implementation have been used and improved from 2002 to 2006.

TABLE 1: POTENTIAL SECURITY AND ACCURACY PROBLEMS AND SOLUTIONS FOR DRE SYSTEMS

	SECURITY/ACCURACY PROBLEMS[6]	POSSIBLE SOLUTIONS
Voting Process	1. System induces voters to under-vote due to misleading ballot layout. For example: 12.3% not voting for US Senator in LA election in 2002. 2. System and software programming errors. 3. Possible software and system tampering by insiders and outsiders, including voters. 4. VVPB being tampered with.	1. Proper ballot layout (for example, one contest per screen or full-face with clear reminders) to avoid unintentional under-voting. 2. Print a VVPB[7] [8]. 3. Print a VVPB. Make sure that the voter's privacy is preserved. 4. Each paper record should have an identifier and/or hashed identifier with the full ballot image to prevent counterfeiting of the VVPB. ▪ There should be a one-to-one correspondence between ballot images and paper records. ▪ All paper records should be sealed. Canvassing or recounting should be held in public.
Tallying individual votes and local consolidation	1) Tallying program has errors (intentional or not). 2) Electronic tallying media is changed during consolidation at a local polling place with multiple machines.	1) Compare "signed-in" voters with the voter registers and total number of cast votes. ▪ Set aside a fixed percentage of randomly selected voting units for the VVPB and electronic tally recounting. ▪ Electronic ballot and paper records from the VVPB should be one-to-one tied with a voting session identifier. 2) Print out each machine tally before consolidation. ▪ Electronic transfer media (e.g. CD-R) should be write-once-read-only not "read/write" flash memory.
Consolidation of local tallies at the central canvassing office	1. Tallying program has errors (un-intentional or intentional). 2. Electronic tally media are altered during consolidation process at a local polling place with multiple machines.	1. Post individual voting unit tally over the web. 2. Electronic transfer media (e.g. CD-R) should be write-once-read-only rather than "read/write" flash memory.

We will explore the issues and solutions outlined in the above table of summary in details in this paper.

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[6] The Machinery of Democracy: Protecting Elections in An Electronic World http://www.brennancenter.org/programs/dem_vr_hava_machineryofdemocracy.html
Residual Votes Attributable to Technology http://journalofpolitics.org/Contents/Vol67/arts672/stewart.pdf

[7] Frequently Asked Questions about DRE Voting Systems http://www.verifiedvoting.org/article.php?id=5018
VVPB (Voter Verified Paper Audit Trail) http://www.bbvforums.org/cgi-bin/forums/board-auth.cgi?file=/73/32943.html
Accurate – A Center for Correct, Usable, Reliable, Auditable, and Transparent Elections http://accurate-voting.org/
Caltech/MIT Voting technology Project – Conference on Voter ID/registration http://www.vote.caltech.edu/

[8] VVPB Update for the VVSG 2005 http://vote.nist.gov/032906VVPB-update-20060317.pdf

Is paper ballot really a better solution than a DRE system with a VVPB?

The answer is obvious if one were given a choice between DRE voting systems without a VVPB and paper ballots. Voters across the country are now aware of the failures of the electronic voting systems without a VVPB. Given such limited choices, the majority of voters would choose to vote by paper ballot.

What if the voters are given a choice between a well-engineered DRE system with VVPB with proven records of accuracy and performance and that of a traditional paper ballot along with its potential pitfalls? The answer may not be so obvious.

When we say "well-engineered DRE system with a VVPB," we are talking about a system that has been proven to provide the following:

1. Voters are given a chance to review their selections on screen as well as on paper. The paper record is not in a continuous roll, but individualized and private.
2. Each electronic ballot, along with the corresponding paper record, is tagged with a private and randomly generated voting session identifier to securely encrypt each ballot.
3. The peace of mind that only a 0% residual vote (unintentional under-votes or over-votes) can bring by using a voter interface that guides the voters like a one-way street.
4. Voters with disabilities can vote independently and privately using the same equipment as all other voters.
5. Voters that express more than 96% confidence in the accuracy of their vote.

In the USA, if paper ballots are to be used by the majority of voters, they must be accompanied by a DRE system, or a ballot-marking setup similar to a DRE system, in order to provide accessibility for up to 20% of currently excluded American voters (US Census of estimated American with disabilities). The well-known ballot-tampering problems associated with the use of conventional paper ballots must be addressed to avoid the pitfalls well known with the paper ballot elections. The following are some of them.

Security Consideration:

- Is there a solution for the "ballot stuffing" and "tampering" problems that have plagued the election world since there has ever been anonymous voting?[9] [10]

Accuracy Consideration:

- Is the 1-3% inevitable unintentional under-voting and over-voting of optical mark-sense tabulation acceptable?
- Are the inherent 0.5% deciphering errors made by the optical scan systems acceptable?

Practicality and Cost Consideration:

- While paper ballots can be hand counted relatively efficiently in parliamentary elections, is hand counting really practical for the complex, US elections?
- What about a larger jurisdiction with 50,000 ballot styles? At the known cost of $300 minimum for preparing each ballot style on paper, is the partial cost in excess of $15 million acceptable for running an election in a single larger jurisdiction?

AVANTE hopes to illustrate in this white paper that both the DRE voting system with a VVPB and the paper ballot system with automatic authentication provisions and a dramatically improved deciphering mechanism can be equally secure and cost effective.

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[9] This declaration by Richard Hayes Phillips reveals disturbing patterns in the ballots he examined from the 2004 Ohio General Election. http://www.bbvforums.org/forums/messages/2197/Declaration_of_Richard_Hayes_Phillips-44286.pdf

[10] "Was the 2004 Election Stolen?" ROBERT F. KENNEDY JR. http://www.rollingstone.com/news/story/10432334/was_the_2004_election_stolen

The choice is not one between either a DRE system or paper ballots. The choice should be what will work best in terms of costs and practicality for a jurisdiction, between a well-engineered DRE system with a VVPB, and a paper ballot solution that can prevent all known paper ballot tampering.

So, is there a reasonable solution to this problem, or are we caught between a DRE voting system that isn't secure and does little to prevent voter errors, and paper ballots, which can be easily tampered with?

There is a tendency for the debate to become distorted based on the volume of errors found in the DRE systems provided by the dominant manufacturers. It has reached the point where even a well-engineered DRE system with a VVPB can't hold its own against the flood of skepticism. New and innovative solution providers, including AVANTE, are not being recognized even when they have continuously held elections with proven successes.

Which voting system is the right one?

The answer is obvious: it depends on what kind of election is being held! The best choice for a voting system depends on the nature of the election.

The development of voting systems has been shaped by a combination of technological evolution and requirements of election laws. We would first like to simplify the discussion by quickly reviewing several types of elections for which the best solution is readily apparent

Parliamentary Election:

For Parliamentary Democracy, voters are asked to choose among a few parties to form its government. Undoubtedly, a paper ballot solution that includes the capability to authenticate ballots and prevent ballot stuffing and tampering is the most cost effective solution for the following reasons:

1. Since there are fewer ballot types, the ballots can be prepared for the extremely low cost of US $0.05-$0.20.
2. Ballots can be counted manually with relative ease.
3. To prevent ballot stuffing and tampering, additional ballot authentication solutions such as those provided by AVANTE's patented technology (US 7,077,313 and 6,893,944) would add another $0.10 to each ballot.

Most democratic nations use paper ballot systems without the authentication technology that is available today. Of course, proper procedures and supervision are needed and a pre-condition to ensure transparent and trustworthy elections, whether with or without the automatic ballot authentication technology.

That leaves us to examine the countries that, like the United States, have extensive contests and choices for the voters to decide on. In a general election, even a small jurisdiction may have as many as 10 or more contests, and each contest could have two to 30 choices. In some states like California, Illinois or New York, there may be as many as 20 to 60 contests.

One can easily visualize the complexity of trying to tabulate votes when there may be as many as 100 or more choices in a single contest. The time and manpower required to manually count the ballots would be virtually impossible if more than a handful of voters turned out.

Maybe we should emphasize that manually counting of all the ballots in an election is not the same as manually recounting a specific race. When a manual recount of a specific race is being conducted, one can ignore all other contests and their corresponding sets of choices. A recount only needs to address one contest. In this way, it is similar to a parliamentary election.

So now we are facing a choice between two solutions that may not be that different. The first solution is a well-engineered and secure DRE system with a VVPB. The other choice is an electronic tabulation of paper ballots.

What is needed is a tamper-resistant DRE system with a VVPB that asks voters to make selections using a user-friendly interface and records their selections in electronic form, verified by a paper record that is reviewed by the voter. If such a solution is reasonably run by a jurisdiction that maintains a degree of separation between the critical functions, the system can be virtually infallible.

Today's paper ballot solutions use electronic tabulation that, unless supported by proper authentication and error-reducing pixel-based deciphering technology, are extremely vulnerable to both tampering and errors, even if the elections are held in the United States[11] [12]. The ballot stuffing and tampering problems continue to cause instability in elections in Africa, South America and Asia (the last election in Mexico is still in limbo).[13] [14]

After providing security against ballot stuffing and tampering, there is only one possible choice for providing handicap-accessibility to the 10% to 20% of the voting population that may need special assistance to vote privately and independently.

Would DRE systems with a VVPB be a good solution as well? It is obvious that, technically, it should work fine. For one thing, it will provide the 10% to 20% of the voting population with visual and physical disabilities the chance to vote without assistance.

If people had faith in their election officials to carry out their duties honestly and correctly, a VVPB would not be necessary. DRE systems without a VVPB have been used in India and Brazil for at least two national elections with hundreds of millions of voters. Of course, it makes anyone with a reasonable understanding of technology and human nature a little nervous. There is also the matter of cost, which we will address in more detail in a separate section.

Presidential elections with many local contests:
Elections like those commonly held in United States are complex, with the number of contests falling anywhere between 10 and 60. Each contest can have anywhere from two to 135 choices. For the county or jurisdiction that is responsible for holding the election, there can be as many as 15 to 15,000 ballot types because of the political sub-divisions.

There are two implications for paper ballot and electronic voting solutions based on the requirements. If one were to use paper ballot solution, each ballot types will have to be pre-printed paper ballot for each type. The costs can be quite substantial. For example, based on the cost of $1,000 to prepare and print each ballot type, a jurisdiction that has 1,000 ballot types will pay $1 million. For a larger jurisdiction with 10,000 ballot types, the cost of preparing paper ballots may be closer to $10 million or more.

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[11] Counting Mark-Sense Ballots - Relating Technology, the Law and Common Sense http://www.cs.uiowa.edu/~jones/voting/optical/
[12] Privacy in Electronic Voting http://privacy.cs.cmu.edu/courses/pad1/lectures/votingShamos.pdf
[13] "Why Mexico Matters?" BY Michael Collins ON 9/3/2006 10:56PM http://www.bradblog.com/?p=3374
[14] "Passions Rise as Mexico Awaits Count" By *Manuel Roig-Franzia* *http://www.washingtonpost.com/wp-dyn/content/article/2006/07/04/AR2006070400966.html*

Of course, in the United States, jurisdictions will still need to provide systems for handicap-accessibility to voters with disabilities based on the Help America Vote Act of 2002. The cost of preparing for each election using a DRE system with a VVPB would be roughly the same for every voter. A detailed cost analysis will be presented in a later section.

Not only is it expensive to prepare and print paper ballots, it is also difficult to handle the logistics for properly distributing the ballots to hundreds and thousands of polling locations.

For a well-engineered DRE system with a VVPB, the cost of preparing the ballot types can be as little as one tenth of what it is for paper ballots. The logistics for distributing the correct ballot types to each polling location will be easy. Each voting unit can have all of the ballots for the jurisdiction loaded onto it pre-distribution. A secure ballot access card is used to call-up the proper ballot for the voters, no matter where they come from.

Security aside, the cost analysis for these systems is confusing because each separate model has different inherent costs for preparing for an election[15] [16].

"Historic" cost data used to compare the operational costs for elections using DRE systems and Optical Mark-sense may be distorted by vendors with inferior technologies:
Many election activist groups have compared the cost of holding an election using DRE systems to that of optical mark-sense systems manufactured by the established and dominant vendors. There were indeed substantial cost differences between using the more established paper versus using the DRE systems. The conclusion made from this data is that running elections using DRE systems is more expensive than using optical paper ballots[17].

While the historic data cannot be argued, the overly-simplified conclusion that holding elections using DRE systems is, by nature, more expensive than using optical paper ballots can be misleading. In fact, New York saved several million dollars by using the ballot-marking device (BMD) technology from AVANTE for their 2006 September Primary Election. At least $10 to $20 million could be saved in New York City alone if another form of BMD, using a "standard" optical paper ballot, is used.

There are three factors that were not considered by the studies that used the historical data.

1) Dramatically increased cost in preparing electronic ballots because of unnecessary difficulties in ballot generation: The "standard" DRE voting systems made by the more established vendors use older software techniques and do not use a database structure. Thusly, their ballot generation programs and methods are extremely cumbersome. Most of the jurisdictions using such system have had to relinquish this task to their vendor. This not only increases costs, but also causes election failures when the vendors cannot meet election deadlines, as seen in the 2006 primary elections across the country.

2) Increased cost of testing and authentication of ballots: The "standard" DRE voting systems made by the dominant vendors with or without VVPB use technologies that are

[15] 2005 Iowa HAVA Voting Systems Master Contract Pricing List
http://www.sos.state.ia.us/pdfs/elections/hava/VotSysMasterContPricingList.pdf
[16] Contract No. 071B6200250 between The State of Michigan and Election Systems and Software
http://www.mi.gov/documents/FINAL_CONTRACT_ACCESSIBLE_VS_6200250_162700_7.pdf
[17] Cost Comparison of Voting Equipment for New York State Touchscreen DRE with VVPB Printer vs. Precinct Based Optical Scan + Ballot Marking Device
http://www.nyvv.org/paperballotCostsMain.shtml

cheaper in order to generate more revenue. They do not use any databases for their voting units, and thus possible automation in testing, such as logic and accuracy (L/A) tests that must be done before and after elections, is rendered impossible. Manual L/A testing is both expensive and prone to errors.

3) Increased costs in corrective actions: With so many errors, many elections and vendors were subjected to legal action. The recounts, consultant studies and legal challenges all contribute to the cost of managing an election.

Tables 2, 3 and 4 are the tabulations done by AVANTE to dissect the real costs of managing an election using "standard" DRE systems made with older technologies in comparison to a well-engineered, secure DRE system with a VVPB. While the data and assumptions are intentionally conservative, the dramatic quantitative differences can be established using published data.

The following summarize the three tables:

1. The cost of running an election using "standard" DRE systems that are integrated with optical centrally-counted mark-sense ballots for a typical 1-million-voter jurisdiction with 1,000 precincts is significantly higher than using AVANTE's more advanced software and database structure. The cost goes down from the typical cost of $2.2 million per election to the new cost of $0.12 million per election (Table 3) based on ballot preparation, pre-and-post election testing and printing of paper ballots. Other factors such as corrective actions will increase the difference even more. DRE system with a VVPB from AVANTE can be 2000 times cheaper than the "standard" DRE solution.

2. In the case of combined use of BMDs, for HAVA accessibility, and precinct-based optical paper ballots for all other voters, the cost difference is even more dramatic. For a "standard" BMD used in conjunction with a non-integrated optical system, the cost can be more than $3 million to run a single election. A completely integrated solution from AVANTE will cost about $0.13 million (Table 4). That is, when using AVANTE's BMD and optical solution, it costs less than 5% as much as the established voting solutions.

3. It is clear that when "standard" DRE systems are used for both HAVA accessibility and precinct-based voting, it costs $2.2 million rather than the $3 million for "standard" BMD solutions (Table 3 and 4).

It is not whether it is a DRE or paper ballot system that determines cost effectiveness; rather it is what ***kind*** of DRE system and what ***kind*** of paper ballot system that is important.

Is the software well designed for ease of ballot preparation? Are the software and system engineered for ease of automated testing and authentication? Are the system and process making both the voters and candidates so confident that recounts and challenges are minimized? Those are the questions that need to be considered.

A well-engineered DRE system with a VVPB costs slightly less than an equally well-engineered optical mark-sense system used in combination with a BMD for HAVA compliance ($2.2 million vs. $3.0 million). Most importantly, the question is good engineering versus bad engineering rather than optical versus DRE.

Poor engineering and design can increase the cost of an election by 20 times or more for the jurisdictions that use them. It has proven in Maryland, Georgia and California. It may be hard to believe the difference, but this fact has been proven with the 2006 primary election in New York.

TABLE 2: Different Optical and DRE Systems Have Different Costs of Ownership				
Costs of Ownership	**"Standard" Optical Mark-Sense (Discrete-sensor and equivalent)**	**AVANTE Optical Mark-Sense (Imaged & Pixel-based)**	**FULL-FACE DRE (Overlay-without "Skip-Contest" choice)**	**FULL-FACE DRE (AVANTE Touch-Screen With "Skip-Contest")**
Ballot Preparation and Generation	• Depending on the vendor, the cost for preparing and generation of ballot may be from $50K to a few $million.	▪ County generates all of its own ballots. ▪ Printing of ballots uses plain paper and laser printing for cost effectiveness.	○ County or vendor generates ballots. ○ Costs may vary from high to low, depending on systems.	➢ County generates and creates a CD or DVD for loading the ballot into voting units. ➢ Cost is low.
Ballot Printing and Distribution	• Smaller jurisdictions may have few ballot styles (ED/AD). The costs for printing may be $0.4-0.8 each or $80K for 100,000 ballots for each election. • Larger jurisdictions may have as many as 50,000 ballot styles (ED/AD and language variations). The costs for printing may be as high as $2-3 million for each election. • Cost for distribution and handling may be high.	▪ Smaller jurisdictions may have few ballot styles (ED/AD). The cost for printing is the same for all jurisdictions at $0.15 each. ▪ Larger jurisdictions may have as many as 50,000 ballot styles (ED/AD and language variations). The cost for printing is still the same at $0.15 each, or $600K for 4 million ballots for each election. ▪ Cost for distribution & handling may be high.	○ Printing of the overlay is the same or similar to the current lever system. ○ Each machine may cost as much as $100 or more. ○ For a jurisdiction of 100 voting units, it might cost $20K. ○ For a large jurisdiction with 10,000 units, the cost could be $1 million or more. ○ Additional paper record rolls at $10 per unit.	➢ $0. No overlay is required. ➢ CD/DVD at $1 each may be used for all voting units. ➢ All voting units are loaded with all of the ballots in the jurisdiction. Ballot access smart cards control the ballot presented to a specific voter. ➢ Additional paper record rolls at $10 per unit.
Absentee Paper Ballots	• Same ballots are used for the absentee and precinct-based voting. Cost is the same as above. • Full-face paper ballot may double the costs.	▪ Generated ballot produces its own absentee ballots at $0.15 each. ▪ Full-face paper ballot may double the costs.	○ The cost for printing may be $0.2-0.8 each, depending on volume & pages. ○ Absentee ballot generation costs $10K to $1 million, depending on the number of ED/AD and languages.	➢ Generated ballot produces its own absentee ballots. ➢ Cost is $0.15 each.
Equipment Costs	• $5-10K each. One per polling location. • At least one handicap-accessible voting unit @ $5-10K each. • NYC may need 6,000 to 7,000 units.	▪ $5-10K each. One per polling location. ▪ At least one handicap-accessible voting unit @ $5-10K each. ▪ NYC may need 6,000 to 7,000 units.	○ $10K each. One for every 400-800 voters, depending on polling hours. ○ NYC may need 10,000 units.	➢ $10K each. One for every 400-800 voters, depending on polling hours. ➢ NYC may need 10,000 units.
Equipment Maintenance and Pre-Election Preparation	• Full maintenance (parts and labor) at 5% purchase cost. • Different test decks for different ED/AD. • Each voting unit has a different test deck.	▪ Full maintenance (parts and labor) at 5% purchase cost. ▪ Different test decks for different ED/AD. ▪ All voting units may use the same test deck.	○ Full maintenance (parts and labor) at 5% purchase cost. ○ Manual LAT at very high costs.	➢ Full maintenance (parts and labor) at 5% purchase cost. ➢ Fully automatic LAT at low cost.
Average Costs per Voter per Election	• $8 for small jurisdiction. • $4 for large jurisdiction.	▪ $5 for small jurisdiction. ▪ $2.5 for large jurisdiction.	○ $6 for small jurisdiction. ○ $3 for large jurisdiction.	➢ $3 for small jurisdiction. ➢ $1.5 for large county.

Table 3: Cost comparison between voting solutions using a DRE system with a VVPB for precinct-based voting, and centrally counted paper ballots for absentee and provisional voting. Depending on the degree of automation in ballot generation and L/A testing, the cost differential is around a factor of 20. AVANTE has proven such a difference in the 2006 primary election in New York State.

	Cost-of-Purchase Per Unit	*Cost-of-System* (Purchased)	Cost-of-Preparing Ballot Per Precinct-Type	Cost-of-Testing L/A for Verification	Cost-of-Printing (Loading) Ballot Per Ballot Type	Operational Cost Per Voter
DRE-Paging with VVPB ("Standard")						
Small Jurisdiction (100 precincts)	$ 4,000	$ 1,600,000.00				
Medium Size Jurisdiction (1,000 precincts)	**$ 4,000**	**$ 16,000,000.00**	**$ 500**	**$ 500**	**$ 100**	**$ 1.10**
Large Jurisdiction (10,000 precincts)	$ 4,000	$ 160,000,000.00				
	(Assumption: 1,000 voters/precinct requiring 4 DRE)				(Assumption: Use of memory module)	
Central Count Optical ("Standard"-Integrated with DRE and/or Precinct-Based Optical)						
Small Jurisdiction (100 precincts)	$ 60,000	$ 120,000.00				
Medium Size Jurisdiction (1,000 precincts)	**$ 60,000**	**$ 120,000.00**	**$ 500**	**$ 500**	**$ 50**	**$ 1.50**
Large Jurisdiction (10,000 precincts)	$ 60,000	$ 120,000.00				
	(Assumption: 2 systems/jurisdiction)		(Assumption: When used with DRE only)		(Assumption: $0.5 per ballot for 100 voters)	
System cost for 1,000 precincts with 1 million voters		***$ 16,120,000.00***	***Cost per election for 1,000 precincts with 1 million voters***			***$ 2,150,000.00***
DRE-Paging with VVPB ("AVANTE")						
Small Jurisdiction (100 precincts)	$ 4,000	$ 1,600,000.00				
Medium Size Jurisdiction (1,000 precincts)	**$ 4,000**	**$ 16,000,000.00**	**$ 50**	**$ 50**	**$ 10**	**$ 0.11**
Large Jurisdiction (10,000 precincts)	$ 4,000	$ 160,000,000.00				
	(Assumption: 1,000 voters/precinct requiring 4 DRE)				(Assumption: Use of CD/DVD)	
DRE-FullFace with VVPB ("AVANTE")						
Small Jurisdiction (100 precincts)	$ 8,000	$ 2,400,000.00				
Medium Size Jurisdiction (1,000 precincts)	**$ 8,000**	**$ 24,000,000.00**	**$ 50**	**$ 50**	**$ 10**	**$ 0.11**
Large Jurisdiction (10,000 precincts)	$ 8,000	$ 240,000,000.00				
	(Assumption: 1,000 voters/precinct requiring 3 DRE-FullFace since it is a faster system)				(Assumption: Use of CD/DVD)	
Central Count Optical ("AVANTE"-Integrated with DRE and/or with Precinct-Based Optical)						
Small Jurisdiction (100 precincts)	$ 30,000	$ 60,000.00				
Medium Size Jurisdiction (1,000 precincts)	**$ 30,000**	**$ 60,000.00**	**$ -**	**$ -**	**$ 10**	**$ 0.10**
Large Jurisdiction (10,000 precincts)	$ 30,000	$ 60,000.00				
	(Assumption: 2 systems/jurisdiction)		(Assumption: When used with DRE only)		(Assumption: $0.1 per ballot for 100 voters)	
Paging DRE System cost *for 1,000 precincts with 1 million voters*		***$ 16,060,000.00***	***Cost per election for 1,000 precincts with 1 million voters***			***$ 120,000.00***

Full-Face DRE System cost *for 1,000 precincst with 1 million voters*	***$ 24,060,000.00***	***Cost per election for 1,000 precincts with 1 million voters***	***$ 120,000.00***

Table 4: Cost comparison between voting solutions using a ballot-marking device and Optical Mark-sense for precinct-based voting and centrally counted paper ballots for absentee and provisional voting. Depending on the degree of automation in ballot generation and L/A testing, the cost differential is around a factor of 20. AVANTE has proven such a difference in the 2006 primary election in New York State.

	Cost-of-Purchase Per Unit	Cost-of-System (Purchased)	Cost-of-Preparing Ballot Per Precinct-Type	Cost-of-Testing L/A for Verification	Cost-of-Printing (Loading) Ballot Per Ballot Type	Operational Cost Per Voter
Ballot Marking Device ("Automarking"-If not completely integrated with Precinct-Based Optical or DRE)						
Small Jurisdiction (100 precincts)	$ 6,000	$ 1,800,000.00				
Medium Size Jurisdiction (1,000 precincts)	**$ 6,000**	**$ 6,000,000.00**	**$ 500**	**$ 500**	**$ 500**	**$ 1.50**
Large Jurisdiction (10,000 precincts)	$ 6,000	$ 180,000,000.00				
	(Assumption: 1,000 voters/precinct)		(Assumption: 100 voters with disabilities/Precinct)			
Precinct-Based Optical ("Standard"-If not completely integrated with "Automarking")						
Small Jurisdiction (100 precincts)	$ 6,000	$ 1,800,000.00				
Medium Size Jurisdiction (1,000 precincts)	**$ 6,000**	**$ 6,000,000.00**	**$ 500**	**$ 500**	**$ 500**	**$ 1.50**
Large Jurisdiction (10,000 precincts)	$ 6,000	$ 180,000,000.00				
	(Assumption: 1,000 voters/precinct)		(Assumption: $0.05 per ballot for all voters with specialized paper and printing)			
Central Count Optical ("Standard"-Integrated with DRE and/or Precinct-Based Optical)						
Small Jurisdiction (100 precincts)	$ 60,000	$ 120,000.00				
Medium Size Jurisdiction (1,000 precincts)	**$ 60,000**	**$ 120,000.00**	**$ -**	**$ -**	**$ 50**	**$ 0.50**
Large Jurisdiction (10,000 precincts)	$ 60,000	$ 120,000.00				
	(Assumption: 2 systems/jurisdiction)		(Assumption: $0.05 per ballot for 100 absentee voters with specialized paper and printing)			
Cost of System for 1,000 Precincts with 1 Million Voters		***$ 12,120,000.00***	***Cost for each election for 1,000 precincts with 1 million voters***			***$ 3,050,000.00***
Ballot Marking Device ("AVANTE"-Integrated with Precinct-Based Optical and/or DRE)						
Small Jurisdiction (100 precincts)	$ 5,000	$ 1,500,000.00				
Medium Size Jurisdiction (1,000 precincts)	**$ 5,000**	**$ 5,000,000.00**	**$ -**	**$ -**	**$ 10**	**$ 0.01**
Large Jurisdiction (10,000 precincts)	$ 5,000	$ 150,000,000.00				
	(Assumption: 1,000 voters/precinct)		(Assumption: 100 voters with disabilities per precinct of 1000 voters)			
Precinct-Based Optical ("AVANTE"-Integrated with BMD and/or DRE)						
Small Jurisdiction (100 precincts)	$ 6,000	$ 1,800,000.00				
Medium Size Jurisdiction (1,000 precincts)	**$ 6,000**	**$ 6,000,000.00**	**$ 50**	**$ 50**	**$ 10**	**$ 0.11**
Large Jurisdiction (10,000 precincts)	$ 6,000	$ 180,000,000.00				
	(Assumption: 1,000 voters/precinct)		(Assumption: Completely integrated semi-automatic ballot generation and automated L/A testing)			
Central Count Optical ("AVANTE"-Integrated with DRE and/or with Precinct-Based Optical)						
Small Jurisdiction (100 precincts)	$ 30,000	$ 60,000.00				
Medium Size Jurisdiction (1,000 precincts)	**$ 30,000**	**$ 60,000.00**	**$ -**	**$ -**	**$ 10**	**$ 0.10**
Large Jurisdiction (10,000 precincts)	$ 30,000	$ 60,000.00				
	(Assumption: 2 systems/jurisdiction)		(Assumption: $0.1 per ballot for 100 absentee voters per precinct of 1000 voters)			
Cost of System for 1,000 Precincts with 1 Million Voters		***$ 11,060,000.00***	***Cost for each election for 1,000 precincts with 1 million voters***			***$ 130,000.00***

What's wrong with the available voting systems with a VVPB? Why is VVPB not implemented satisfactorily?

Electronic balloting machines that record votes electronically while implementing no other independent auditing methods should scare anyone that has any understanding of technology and the election process. Scientists have pushed for what is now called a VVPB. Computer scientists do not usually become activists. Most of them became involved because of their deep understanding of how easy it is to tamper with an electronic system if there is no independent audit trail. This common-sense approach should appeal to almost anyone, but unexpectedly, the majority of election officials oppose it.

There are new market entries such as AVANTE, Accupoll, Truvote and Populex that provide DRE with VVPB with different approaches since 2001. They can hardly make a dent in the marketplace. All but a few election officials have completely rebuffed these newcomers.

There may be two key reasons. The new market entries with new technologies are "Johnny-come-lately" in terms of developing relationships with election officials. May be in an effort to help their old friends or simply being conservative, election officials put up hurdles that the new entries will never be able to leap over. Some notable hurdles: three to five years of previous election experience (some California counties), at least $1 million in previous sales of the equipment being proposed (Ohio)[18], at least one or more elections held with the equipment being proposed (Washington), etc.

There goes any possible chance for innovation from the newcomers in the election industry.

The second reason for the difficulty in obtaining market acceptance for the VVPB is that it will make the election process more cumbersome. All election officials love elections with large margins. Close elections on the other hand means recounts and challenges. An independent audit trail, such as paper records, will just invite recounts under public supervision.

An unexpected opposition comes from notably some visually impaired voters. Even though it is clear that blind voters can hear the reading back of a paper record, objections are still being raised by at least one prominent blind voter. The logic of such objection is interesting. It is equivalent to saying that, since the blind voters cannot "see" the paper records, sighted voters should not be allowed VVPB. Of course, the blind voters not being able to "see" the ballot on the touch-screen are thankful for the ability to vote independently by listening to the ballot.

With such strong market forces, the newcomers in the election industry are left at the front doors struggling to get in.

Most of the concerned citizens and scientists left with no other avenue and end up appealing to state election officials. They hope that the officials will demand that the established companies provide more secure solutions, including independent paper records and an audit trail.

After tremendous effort and education, more than 27 states now require some form of paper audit trail and in most states, the voters must first verify these paper records. After extraneous objections and lobbying efforts in opposition, the leading manufacturers of voting machines reluctantly agreed to produce or retrofit their DRE with VVPB.

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[18] Vendor Proposal Evaluation Findings Report & Addendum, Statewide Voting System(s), Ohio Secretary of State J. Kenneth Blackwell, Prepared by Nola Haug, Report Date: August 15, 2003, Addendum Date: September 10, 2003.

Instead of following the advice provided by AVANTE in its many white papers and as demonstrated in elections and public equipment expositions, all of the established companies collectively designed and provided the state required voter-verifiable paper ballot in a continuous roll!

By using a reel-to-reel continuous roll of paper for the audit trail, the voter's privacy is being threatened as has been pointed out by voters and scientists alike.[19] In addition, the effort and design of trying to wind up a few hundred feet of paper into a roll tends to increase the frequency of printer paper jams. To minimize such unavoidable paper jamming, paper roll is limited to less than 300 ft. A 250-ft paper roll is unable to accommodate a single election in most states. Changing paper roll during election induces yet more errors.

Some of the election officials, even though they understood the potential privacy violation, agreed to accept these systems. The rationale is exemplified by the following approval of such systems in California: "In the ideal world, we would all agree that a continuous roll of paper audit trail should not be used. Since the vendor is not able to produce such a system, we have no choice but to allow the paper audit trail to be produced in a continuous roll." This is paraphrasing, but it is not a joke. It really happened!

Only the election officials in New York had the guts to tell these largest election equipment manufacturers not to show up if they could not produce a paper record that is individualized, like that produced by AVANTE. Suddenly, all of the claimed technical hurdles and difficulties of these manufacturers disappeared. They are now all capable of producing paper records that will not threaten the privacy of the voters.

The rest of the story can be read from news media over the last 2 years, culminating with the spectacular failure in Ohio. One may wonder whether these failures are what the manufacturers wanted. Now the vendors and their friends can all tell the story that "see, we told you VVPB wouldn't work."

After being frustrated by the leading voting solution providers for electronic voting, how can anyone blame the scientists of the United States that have been pushing for DRE systems with a VVPB for throwing in the towel. The only alternative left is that of paper ballots. Paper ballot systems that are read by optical scanners may also have security flaws[20]. At least voters are assured of the availability of a paper audit trail. Of course, there are high hurdles and costs put up by some state election officials to prevent manual recounts of the paper ballots as well.

Counting Methods and Potential Accuracy Problems of Using Paper Ballots:
Are paper ballots and hand counting the best solution?

Assuming one addressed the potential security issues like ballot stuffing and tampering, paper ballots and manual hand counting work well only for countries with parliamentary elections. In complex elections such as those in the United States, manual counting may not be practical.

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[19] "Voting Devices for Disabled Draw Praise From All Sides"
http://www.nytimes.com/2006/09/14/nyregion/14handicapped.html?ex=1160452800&en=0cf1dc993b6058de&ei=5070
"Voters with Disabilities Use New Machines in New York Primary-*Accessible touch screens, borough-wide vote centers attract others as well"*
http://electionline.org/Newsletters/tabid/87/ctl/Detail/mid/643/xmid/207/xmfid/3/Default.aspx
Analysis of Volume Testing of the AccuVote TSx / AccuView, Matt Bishop, Loretta Guarino, David Jefferson, David Wagner, Voting Systems Technology Assessment Advisory Board with assistance from statistician Michael Orkin (Managing Scientist, Exponent), October 11, 2005.

[20] Security Alert: July 4, 2005 - Critical Security Issues with Diebold Optical Scan Design
http://www.blackboxvoting.org/BBVreport.pdf

Some election officials claim that in their post-election audit process, the hand counting of 100 paper records took as long as 5 days for a team of 4 or more people.

While the time and effort of manual counting is acceptable when only one contest is being challenged, it is almost impossible to count every single contest using such a method for large number of ballots. Some automatic-tabulation optical scanners must be used to decipher the marked ballots automatically. Professor Doug Jones of University of Iowa has one of the more comprehensive analyses of potential errors found in optical mark-sense readers.

It is also well known that optical scanning, or similar technologies used to score the SAT tests, have produced as much as a 0.5% error rate when the papers are saturated with the moisture in the air on rainy days.

While the federal voluntary voting system standards (VSS) of 2002, which must be met by all voting systems, requires all systems to make less than 1 mistake in 1,500,000 marks, there are few optical systems that can operate correctly with less than 1 error in a few thousand.

To ensure this kind of accuracy in both testing and in the actual elections, optical scanners must be able to adapt to the contraction or expansion of the paper.

In order to evaluate voter intent when the markings on the ballot are below the threshold of mark-sense detection (that is, they're too light or inks that are not suitable) the system must be able to handle such possibilities to ensure that none of cast votes are counted incorrectly.

All of the above improvements have been delineated by a series of US patents (US 6,892,944 and 7,098,793) issued to AVANTE.

Systems incorporating these improvements were proven to achieve a 0% error rate in 1,500,000 markings during the Independent Testing Authority certification process in AVANTE OPTICAL VOTE-TRAKKER mark-sense voting systems[21].

The ability to resolve the positions and "pixel counts" of marks solves the accuracy problems inherent in our paper ballot and optical scanning solution. It makes the optical mark-sense voting systems such as the OPTICAL VOTE-TRAKKER and other voting systems that use such technologies meet the stringent 2002 Federal VSS.

How about ballot stuffing and ballot tampering?

Even if we can scan and decipher paper ballots accurately, we are still left to contend with the potential of ballot stuffing and tampering.

Professor Michael I. Shamos is an opponent to any use of paper records or paper ballots. He describes going back to use paper ballot as: "Ridiculous!"[22].

[21] Optical VOTE-TRAKKER™: A "Mark-Sense" Absentee & Precinct Based Voting System That Minimizes Both Voter and System Errors
http://www.verifiedvoting.org/downloads/OpticalVote-Trakker.pdf

[22] Paper v. Electronic Voting Records – An Assessment
http://euro.ecom.cmu.edu/people/faculty/mshamos/paper.htm
Electronic Voting (17-803, 17-400)
http://euro.ecom.cmu.edu/program/courses/tcr17-803/

The paper ballot solution can be made to be not so "ridiculous" when enhanced with authentication technology and careful control of chain-of-custody, though this may not be the perfect solution either.

The ballot-stuffing problem has been around since the introduction of the "Australian" style of secret paper ballot. More in-depth documentation and related historical voting problems can be found in a 1988 study[23] and a recent book by Roy Saltman[24]. While these problems may be alleviated by controlled election processes and observations, they have not been proven to be very effective in most countries.

Paper ballots can be easily duplicated and faked. This can happen anytime between the closing of the polls and the actual counting of the ballots. The larger the geographic distribution of the population and the poorer the means of communication, the more potential for tampering exists. And of course, there is always a tendency to accuse the party that controlled the process.

Even if one uses the precinct-based optical mark-sense systems that produce and post election results immediately, there is still the possible introduction of extra absentee ballots. Of course, the automatic deciphering of paper ballots implies the existence of another electronic vote-tallying method. Like any electronic voting system, the vulnerabilities in this system are much the same as in the DRE system. Many of the elements that AVANTE uses to solve the security and accuracy issues in its DRE system patents are also applicable in resolving the problems with optical-ballot voting solutions[25] [26].

While it is true that one can recount the paper ballots when in doubt or in a close race, if there is a missing link in the chain-of-custody and partisan control of the election process, there is always a potential accusation of ballot stuffing or tampering.

AVANTE has invented a method to prevent ballot stuffing[27]. Each ballot is pre-printed with a randomly generated ballot identifier to authenticate the ballot. This is a better method than the use of secret or "hard-to-reproduce" paper or ballot identification marks. This patented technology prevents tampering by an outsider, though insider tampering must still be guarded against. We have to control the process of ballot distribution in order to detect the more sophisticated insider tampering.

For the central count of absentee ballots, AVANTE has a patented technology for reading all ballots without the need for individual sorting and proper orientation of the ballots, thus minimizing the opportunity for tampering. Also, the system takes a full picture of each individual ballot for subsequent evaluation[28].

Still, if there is a process involving a human, there is always a chance of tampering. Without using a randomly generated number for ballot authentication and the ability to capture and

[23] Accuracy, Integrity, and Security in Computerized Vote-Tallying
http://www.itl.nist.gov/lab/specpubs/500-158.htm
[24] The History and Politics of Voting Technology
http://www.palgrave-usa.com/catalog/product.aspx?isbn=1403963924&printer=yes&
[25] US Patent 7,036,730 – Electronic Voting Apparatus, System and Method
http://portal.uspto.gov/external/portal/!ut/p/_s.7_0_A/7_0_CH/.cmd/ad/.ar/sa.getBib/.ps/N/.c/6_0_69/.ce/7_0_3AB/.p/5_0_341/.d/5#7_0_3AB
[26] US Patent Application 10/255,348 - Electronic Voting Apparatus, System and Method
http://portal.uspto.gov/external/portal/!ut/p/_s.7_0_A/7_0_CH/.cmd/ad/.ar/sa.getBib/.ps/N/.c/6_0_69/.ce/7_0_3AB/.p/5_0_341/.d/4#7_0_3AB
[27] US Patent 6,892,944 - Electronic Voting Apparatus, System and Method for Optically Scanned Ballot
http://portal.uspto.gov/external/portal/!ut/p/_s.7_0_A/7_0_CH/.cmd/ad/.ar/sa.getBib/.ps/N/.c/6_0_69/.ce/7_0_3AB/.p/5_0_341/.d/2#7_0_3AB
[28] US patent 7,077,313 - Electronic Voting Apparatus, System and Method for Optically Scanned Ballot
http://portal.uspto.gov/external/portal/!ut/p/_s.7_0_A/7_0_CH/.cmd/ad/.ar/sa.getBib/.ps/N/.c/6_0_69/.ce/7_0_3AB/.p/5_0_341/.d/0#7_0_3AB

protect the images of all ballots for ease of inspection, paper ballot voting methods can hardly be considered secure[29] [30].

Table 5 below is a summary of the potential problems facing the use of paper ballots, along with a few possible solutions.

TABLE 5: PAPER BALLOT-POTENTIAL PROBLEMS AND SOLUTIONS

	ACCURACY/SECURITY PROBLEMS	POSSIBLE SOLUTIONS
Voting Process	1. Marking not adequate for automatic mark-sense scanner. 2. Marking incorrectly with a cross or checkmark on or near the choice, rather than filling in the oval. 3. Marking incorrectly by circling around the choice or oval rather than filling in the oval. 4. Ballot stuffing. a. At poll sites. b. During transport. c. At the tabulation centers. 5. Accessibility.	1. Hand counting, or ▪ Technology can read both light and dark (smudged) marks. 2. Hand counting, or ▪ Technology can read both light and dark (smudged) marks. 3. Hand counting, or ▪ Technology that can "pull" such ballots for manual counting. 4. Assuming independent observers are available. a. Have observers at poll sites. b. Count the ballots at poll sites. c. Count the ballots at poll sites under independent observation. 5. Use a DRE or Ballot Marking Device with accessibility provisions.
Counting ballots using manual "hand counting"	1) Authenticating the ballots to prevent the inclusion of "fake" ballots. 2) Lack of transparency and a coercion-free environment. 3) Overly labor-intensive for large and complicated ballots. 4) Human errors in counting more complicated ballots.	1) Ballots having a unique identifier that cannot be copied and there are no means for correlating them. Printing with security marks or specialty papers may not be enough. 2) Coercion-free environment is a pre-requisite for manual hand counting. 3) Most US elections may be difficult to hand count. More suitable for parliamentary type of elections. 4) Confirm ballots in groups of 10. That is, it is very difficult if not impossible.
Counting ballots using automatic mark-sense reader	1. Authenticating the ballot against voters or insiders submitting "fake" ballots. 2. Software and machine error (technical and intentional). 3. Machine error of under counting. 4. Machine error of over counting.	1. Ballots having a unique identifier and the means to be authenticated before counting. Printed sequential numbering and other marks are not good enough. 2. Make an image of all ballots and allow public viewing of all ballots during a special public confirmation. May use sequential viewing to allow public to manually tabulate as they see fit. 3. Under voted ballot-contest images should be reviewed manually with public observation. 4. Over voted ballot-contest images should be reviewed manually with public observation.
Tally Consolidation	1) Consolidation "math/programming" (intentional or human) error.	1) Publish all local tallies at the poll sites immediately after public tallying. ▪ Publish all images of local tallying sheets. ▪ Transmit all local tallies and images of tallying sheets to central office in "real-time."

[29] Is Buying Optical Mark-Sense Voting Systems Today a Good Idea Until DRE Voting Systems Scrutiny is Over? http://www.vote-trakker.com/optical%20vs%20DRE.PDF

[30] Optical VOTE-TRAKKER™: A "Mark-Sense" Absentee & Precinct Based Voting System That Minimizes Both Voter and System Errors http://www.vote-trakker.com/White%20Papers/OPTICAL%20VOTE-TRAKKER%20MINIMIZING%20VOTERS%20AND%20SYSTEM%20ERRORS.pdf

How About Accessibility For Voters with Disabilities?

Standard paper ballots may not be accessible to as many as 20% of voters, that is, those with some form of disability. There are three ways for jurisdictions to say that they have provided handicap-accessible voting to its citizens, and so satisfy the Federal HAVA requirements.

1. Place a DRE system with some handicap-accessible features (mostly voice assistance for visually impaired voters) in each polling location[31].
2. Place a BMD with handicap-accessible features in each polling location. The BMD assists the voters to mark their ballots automatically and independently[32].
   - Use of a phone voting solution with voice assistance to provide limited accessibility (mostly for the visually impaired, not for the physical disabled). This is a special form of BMD[33].

Both of the above solutions can be improved to provide the widest accessibility to both visually impaired voters and physically impaired voters with sight. The implication of combining two different solutions may increase costs significantly (refer to earlier section on cost analysis and implications)

Table 6 below is a summary of the accessibility features that may be incorporated for the precinct-based optical mark-sense and precinct-based DRE voting systems.

TABLE 6: DRE VS MARK-SENSE BALLOT SYSTEM ACCESSIBILITY

	PRECINCT-BASED OPTICAL MARK-SENSE	PRECINCT-BASED DRE
1. Voters that are blind and visually Impaired	▪ Not possible without assistance.	▪ All DRE systems are capable of assisting blind visually impaired voters to vote independently and privately.
Possible Solutions	➢ Supplemental use ballot-marking device with handicap-accessible functions. ❑ AVANTE BMD and OPTICAL VOTE-TRAKKER used for 2006 NY Primary elections.[34] (US 6,892,944; 7,077,313 and other pending patents).	➢ Use of handicap-accessible VVPB. ❑ Accessible VVPB used in the Early Voting of 2002 Sacramento CA General Election and 4 jurisdiction in 2003 General Election in CT. (US 7,036,730; allowed 10/255,348 and other pending patents).
2. Voters with physical disabilities	▪ Not possible without assistance.	▪ Most DRE systems are capable of assisting blind visually impaired voters to vote independently and privately.
Possible Solutions	➢ Supplemental use ballot-marking device with handicap-accessible functions. ❑ AVANTE BMD and OPTICAL VOTE-TRAKKER used for 2006 NY Primary elections. (US 6,892,944; 7,077,313 and other pending patents).	➢ Use of handicap-accessible VVPB. ❑ Accessible VVPB used in the Early Voting of 2002 Sacramento CA General Election and 4 jurisdiction in 2003 General Election in CT. (US 7,036,730; allowed 10/255,348 and other pending patents).

[31] Accessible voting With voter verifiable Paper Records in DRE Voting Systems http://www.vote-trakker.com/White%20Papers/ACCESSIBILE%20VOTING%20with%20voter%20verifiable%20paper%20records%20in%20DRE%20Voting%20System.pdf

[32] Accessible Voting Integrating the Touch-Screen Accessibility of DRE System with the Optical Scanning Paper Ballots http://www.vote-trakker.com/accessible_optical_voting.html

[33] IVS LLC | Vote by Phone Results http://www.uhavavote.org/vendorfair/survey_results/ivsphone_results.html Vermont's Vote-By-Phone (At the Polls) Voting System http://vermont-elections.org/elections1/VoteByPhone.html

[34] "Voting Devices for Disabled Draw Praise From All Sides" http://www.nytimes.com/2006/09/14/nyregion/14handicapped.html?ex=1160452800&en=0cf1dc993b6058de&ei=5070 "Voters with Disabilities Use New Machines in New York Primary-*Accessible touch screens, borough-wide vote centers attract others as well"* *http://electionline.org/Newsletters/tabid/87/ctl/Detail/mid/643/xmid/207/xmfid/3/Default.aspx*

Is There a Perfect Voting Solution?
The answer is obviously no.

However, as discussed in the earlier sections, both the DRE system with a VVPB and the Optical Mark-Sense paper ballot system with ballot marking accessibility can be improved with currently available and proven technologies to address most of the known problems of security and accuracy to come close to be a perfect voting solution.

Table 7 is a summary of security and vulnerability issues of DRE and Optical voting systems and possible solutions. All of the solutions listed have been proven in actual elections in the United States. However, they may be one of the best-kept secrets.

TABLE 7: DRE VS MARK-SENSE BALLOT SYSTEM SECURITY COMPARISON

	PRECINCT-BASED OPTICAL MARK-SENSE	PRECINT-BASED DRE
1. Ballot Stuffing or Fake Ballots	▪ This problem has been around since the use of secret paper ballots. ▪ Error rate cannot be assessed. Many elections have been stolen.	▪ Systems with weaker security have been confirmed to be vulnerable to tampering.
Possible Solutions	➢ Use of special ballot marks and/or papers. ➢ Careful process control and separation of operations. ➢ Use of ballot authentication identifier (e.g. randomly generated "number"). ❑ Solutions have been proven and used in AVANTE BMD and OPTICAL VOTE-TRAKKER used for 2006 NY Primary elections. (US 6,892,944; 7,077,313 and other pending patents).	➢ Use of a VVPB. ➢ Paper records are tied to electronic records with a tracking identifier. ➢ Use encryption and check codes for ballots. ➢ Careful process control and separation of operations. ❑ 0% error rate proven with a VVPB used in the Early Voting of 2002 Sacramento CA General Election and 4 jurisdiction in 2003 General Election in CT. (US 7,036,730; allowed 10/255,348 and other pending patents).
2. Tabulation Tampering and Ballot Tampering	▪ Modification of ballots before counting. ▪ Add or change ballots during the central count. ▪ Error rate cannot be assessed. Many elections have been stolen.	▪ Data transfer media uses flash and other modifiable memory.
Possible Solutions	➢ Scan and report all absentee ballots when they are sent. ➢ Segregated responsibility for ballot handling and management. ➢ Detailed audit log. ❑ Solutions have been proven and used in AVANTE BMD and OPTICAL VOTE-TRAKKER used for 2006 NY Primary elections. (US 6,892,944; 7,077,313 and other pending patents).	➢ Use encryption and check codes for ballots. ➢ Careful process control and segregation of operations. ➢ Use write-once-read-many WORM for data transfer from voting units to central ballot tabulation. ❑ 0% error rate proven with a VVPB used in the Early Voting of 2002 Sacramento CA General Election and 4 jurisdiction in 2003 General Election in CT. (US 7,036,730; allowed 10/255,348 and other pending patents).

Table 8 below is a summary of the errors and error rates that are associated with optical paper ballots and DRE voting solutions along with the possible solutions. All of the solutions listed have also been proven in actual elections in United States. Again, they may be yet another one of the best-kept secrets.

TABLE 8: DRE VS MARK-SENSE BALLOT SYSTEM ACCURACY/ERROR

	PRECINCT-BASED OPTICAL MARK-SENSE	PRECINT-BASED DRE
1. Voter Error ○ Induced by unclear instructions or unnecessary marking requirements. ○ Insufficient voter "training" or "education" such as insufficient and wrong markings.	▪ 1-5% under-voted ballots for the top-tier contests. ▪ Can be as great as 20% (2006 WA primary election for requiring selection of party of affiliation). ▪ Minor (<1%) percentage of over-voted ballots.	▪ 12.3% forgot to vote for US senator in LA in 2000, later attributed to split screen contests. ▪ Typically 3+/-% under-voted ballots for the top-tier contests. ▪ 0% over-voted contests.
Possible Solutions	➢ More voter outreach and polling place demonstration. ➢ Incorporation of "Skip-Contest" choice. ❑ 0.5-1% residual votes for the top of the ticket (combination of under votes and over votes) may be achievable.	➢ Incorporation of "one-contest per screen" paging screen system. ➢ Incorporation of high-contrast reminders. Ask voters to acknowledge their intention of not voting on the contests without selections for "full-face" ballot. ➢ Incorporation of "Skip-Contest" choice. ❑ 0% unintentional under-vote has been consistently achieved for 35 elections with AVANTE VOTE-TRAKKER DRE voting solutions (US 7,036,730; allowed 10/255,348 and other pending patents).
2. Write-in Error	▪ Typically rejected mechanically or separately handled by manual count.	▪ All DRE systems provide ease of recording and reporting of write-ins.
Possible Solutions	➢ Image the ballot and decipher the handwriting manually. ❑ AVANTE OPTICAL VOTE-TRAKKER. (US 6,892,944; 7,077,313 and other pending patents).	❑ Current solutions by all vendors are adequate.
3. Hardware/Software Error	▪ Unable to resolve light markings. ▪ Unable to resolve slight smudge. ▪ Discrete sensors with fixed threshold of reading marks. ▪ May be as high as 0.5% error rate.	▪ Machine calibration errors. ▪ Machine programming errors.
Possible Solutions	➢ Use fiducial markings and scaling to accommodate paper dimensional changes and local variation. ❑ Less than one error out of 1,500,000 marks has been proven in ITA testing based on 2002 VSS with AVANTE OPTICAL VOTE-TRAKKER. (US 6,892,944; 7,077,313 and other pending patents).	➢ Only certified and tested software is used. ➢ Full L&A testing before/after each election for each and every voting units. ➢ Use of VVPB. ❑ 0% error rates have been "proven" with a handicap-accessible VVPB consistently for 35 elections with AVANTE VOTE-TRAKKER DRE voting solutions (US 7,036,730; allowed 10/255,348 and other pending patents).
4. System and Technology Error	▪ Paper misalignment. ▪ Timing error due to paper shrinkage or expansion. ▪ Unable to recognize some inks. ▪ Unable to resolve paper folding and distortion.	▪ Lost data. ▪ Data integrity cannot be ascertained.
Possible Solutions	➢ Use fiducial markings and scaling to accommodate paper dimensional changes and local variation. ❑ Less than one error out of 1,500,000 marks had been proven with AVANTE OPTICAL VOTE-TRAKKER. (US 6,892,944; 7,077,313 and other pending patents).	➢ Use of VVPB. ➢ Use ballot data tagging, encryption and/or check code for each ballot. ❑ 0% error rates have been "proven" with accessible VVPB consistently for 35 elections with AVANTE VOTE-TRAKKER DRE voting solutions (US 7,036,730; allowed 10/255,348 and other pending patents).

Another subset of DRE systems is those using a full-face format that is favored by New York[35], New Jersey, Delaware, and part of Pennsylvania. The full-face format is used in the original "direct recording mechanical" (DRM) lever voting system. Since all of the contests are presented in a single layout over a 2-3 ft width of display, there is a potential and proven higher rate of under-voted contests.

When converting from DRM to DRE with a VVPB, the high rate of under-voting can be worsened. The more traditional full-face DRE system with a plastic overlay cannot provide any assistance in alerting voters of possible under-voted contests. These potential problems and historic data are discussed and illustrated in one of the Brennan Center reports[36].

Again, with careful engineering, even the full-face DRE can be used with 0% unintentional under votes. Figure 1 below is an illustration of how the AVANTE full-face DRE system with VVPB eliminates the problem of unintentional under voting.

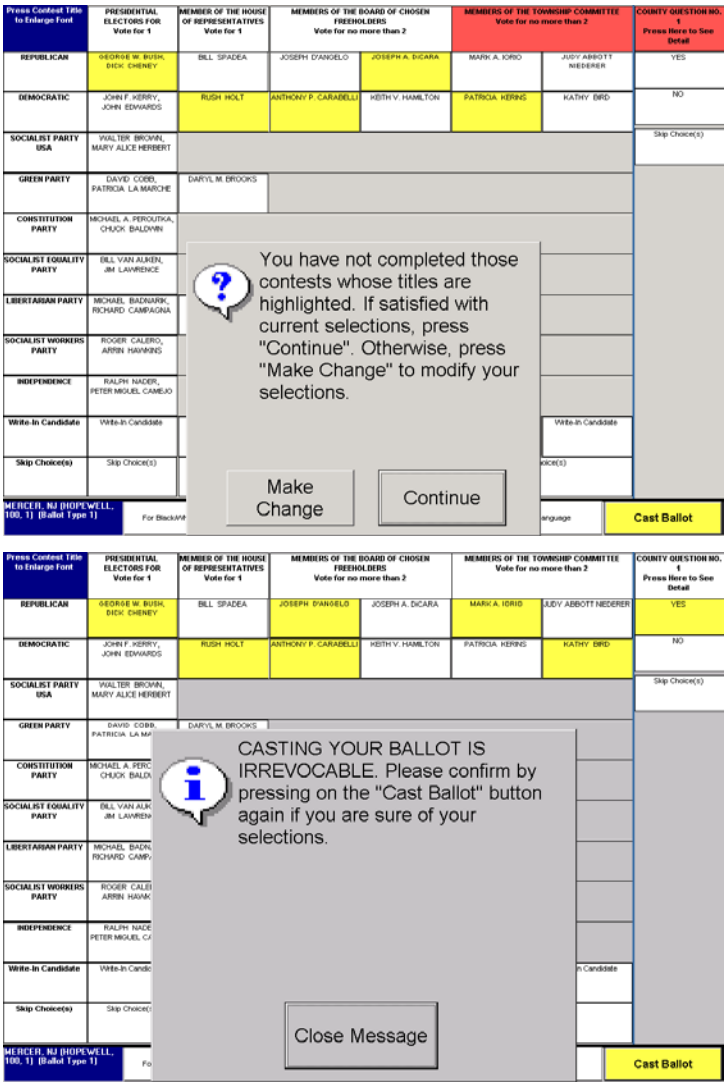

Figure 1: Here is the way that AVANTE handles the unintentional undervoting issue in the full-face format.

1. AVANTE continues to provide "Skip Contest" as one of the choices for each of the contests. That is, if the voter wishes not to vote on any specific contest, they can simply touch that selection.
2. AVANTE provides a reminder screen to prevent unintentional under voting and to ensure positive confirmation that the voter wishes to skip over some contests:
   - If the voter wishes to "Cast Ballot" and the ballot is completed (including "Skip Contest" choices), the screen will simply remind the voter that "Casting ballot is irrevocable...." as required by the 2002 and 2005 VSS.
   - If the voter touches "Cast Ballot" without finishing all of the contests, the same reminder screen will appear. In addition, all those contests that are under-voted will be highlighted with a pink color.
   - If the voter wishes to make more choices, when choices are added to an under voted contest, the color of the contest title will revert to "white" like the rest of the contests.
   - If the voter decides to "Cast Ballot" even with the reminder screen telling him/her about the under voted contests, they can do so by confirming by touching the "Continue" button to acknowledge the fact that they really intend to under vote the contest. All of the "not voted' contests will be indicated as "Skip Contest" in the final review screen.
   - By pressing "Cast Ballot" again, the system will register the remainder of the under-voted contests as "Skip Contest" selections same as the final review screen. That is, the unintentional under votes become intentional under votes.

[35] New York State Voting System Qualification – Master Test Plan (Draft) http://www.elections.state.ny.us/NYSBOE/hava/MasterTestPlan0_1NY_1.pdf

[36] The Machinery of Democracy: Voting System Usability http://www.brennancenter.org/programs/dem_vr_hava_modusability.html

Table 9 is a summary of the potential errors and potential solutions for using different types of full-face ballots of electronic optical scanning type or direct recording electronic type with VVPB.

TABLE 9: ERROR RATES FOR DIFFERENT OPTICAL AND DRE SYSTEMS

Potential Errors	OPTICAL MARK-SENSE (Discrete-sensor)	AVANTE OPTICAL MARK-SENSE (Imaged and Pixel-based)	FULL-FACE DRE (Overlay-without "Skip-Contest" Management)	FULL-FACE DRE (AVANTE Touch-Screen With "Skip-Contest")
Over-vote	• Inherent **machine error** rate of up to 1/1000. • Some **voter error** may be corrected with NY election laws for "telling" voters which specific contest is being over-voted. Assuming, of course, the voters having patience and time to correct their ballot.	➢ Inherent **machine error** rate may be reduced to almost 0% with pixel-based imaging system. ➢ Some **voter error** may be corrected with NY election laws of "telling" voters which specific contest is being over-voted. Assuming of course the voters having patient and time to correct their ballot.	○ Over-vote is prevented.	○ Over-vote is prevented.
Under-Vote	• Inherent **machine error** rate of up to 1/1000. • Some **voter errors** may be corrected with NY election laws of "telling" voters which specific contest is being under-voted. Assuming, of course, the voters having patience and time to correct their ballot.	➢ Inherent **machine error** rate may be reduced to almost 0% with pixel-based imaging system. ➢ Some **voter errors** may be corrected with NY election laws of "telling" voters which specific contest is being under-voted. Assuming, of course, the voters having patience and time to correct their ballot.	○ The existing touch-pad systems with overlays cannot be highlighted to help the voters to correct their unintentional undervotes. Undervoted contests tend to be high.	➢ Voter is encouraged to use "Skip Contest" to indicate their intent to under vote. ➢ Unintentional under-voted contests are highlighted with color boxes and warning messages on review summary screen. Warning highlight color will disappear when full selections are made or the voter confirms his/her intent to under vote. 0% unintentional under-vote is achieved.

CONCLUSIONS

The following points are the highlights of the discussion made in this white paper.

1. Not all electronic voting systems are the same. Direct Recording Electronic voting systems with a properly engineered Voter-Verified Paper Ballot can and have been proven to work flawlessly.
2. Both full-face and paging DRE systems with a VVPB can work equally well when properly designed and engineered, with 0% unintentional under-votes or voter errors.
3. Paper ballot voting systems with optical scanning technology and DRE with VVPB voting systems have different errors and security issues. Both paper ballot and DRE with VVPB systems must be carefully managed with public supervision to provide secure, transparent and cost-effective election.
4. The choice for better voting solution is not between paper ballot systems and DRE systems with VVPB. It is a choice between properly designed and engineered solutions and that of inadequately or poorly designed and engineered solutions.
5. The cost of ownership can differ by as much as 20 times between a properly designed and integrated voting solution and system and those that has been inadequately engineered with the minimal capability for automation in ballot generation, tabulation and testing.