Submission to the New York State Board of Elections on the Proposed Standard for the Minimum Number of Voting Machines

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Introduction

In April 2007, the New York State Board of Elections formally proposed a standard for the minimum number of voting machines required in each polling place as is required by New York State Election Law §7-203 (2)[1]:

> 7-203 (2) Notwithstanding any provision of law to the contrary, the state board of elections shall establish, in accordance with subdivision four of section 3-100 of this chapter, for each election, the minimum number of voting machines required in each polling place and the maximum number of voters that can vote on one voting machine. Such minimum number of voting machines shall be based on the voting machine in use, taking into account machine functionality and capability and the need for efficient and orderly elections and, in the case of a general or special election, the number of registered voters, excluding voters in inactive status, in the election district or, in the case of a primary election, the number of enrolled voters, excluding voters in inactive status, therein.

Unfortunately, the standard the Board proposed of one DRE for every 550 registered voters is demonstrably far too high and will condemn voters in New York State to long lines and waiting times at the polls, and the resulting voter disenfranchisement that comes with it.

Since the discussion on this standard began in 2006, New Yorkers for Verified Voting has authored three separate reports which have been formally submitted to the Board for consideration. This final paper will discuss some new material and review the findings from our previous reports. The reports themselves are included in the Appendix, and should be considered part of this submission.

The findings from our earlier reports are clear. Computer simulations of voter arrival times, surveys of other states DRE to voter ratio, and data collected during the 2006 General Election from an upstate New York county all demonstrate that *no more than 200 registered voters can be served by a single DRE*.

There is abundant evidence that the Board's current proposal of 550 voters per DRE is a recipe for disaster. If the current proposal is imprudently adopted and the State Board of Elections is called to account for the resulting debacle, they will not be able to say "we had no way to know this would happen."

Four Components of this Submission

This paper is divided into four sections plus Appendices which contain reports previously submitted to the New York State Board of Elections on to this topic:

- Refutation of the formula used to determine the Board's proposed 550 voters per DRE ratio.
- Analysis of the actual ratio of voters per DRE using queuing theory.
- The Columbia County study of voter arrival times in the 2006 General Election.
- Voter to DRE ratios used by other states.
- Conclusions

[1] http://www.elections.state.ny.us/NYSBOE/hava/Voting_Machines/6210.19Regs05302007.pdf

1) Refutation of the Formula Used to Determine the Board's Proposed 550 Voters per DRE

How did the New York State Board of Elections determine that 550 voters per DRE should be the proposed standard? It applied a simple formula to data results from a study it commissioned from American Institute of Research (AIR).[2] Unfortunately, the Board is employing a flawed formula using flawed data from a flawed study.

Problems with the AIR study

The AIR study, which was never completed but left in "Draft" status,[3] drew much criticism from the public for its failure to ensure that DRE voters checked VVPATs, sloppy time keeping methodology, and other study design problems. Even AIR itself acknowledged multiple limitations of the study, such as its lack of consideration for the impact of voters with disabilities on waiting times.[4] But the fundamental flaw of the AIR study is that it does not address the critical question: *How many voters can use each voting machine in one day?*

The AIR study neither takes account of nor makes any attempt to reconcile the impact of uneven voter arrival rates and the well known problem that a large percentage of voters arrive during the peak periods of the Election Day in the morning and early evening hours. Rather, AIR measures only the time spent by individuals on each voting machine. It then divides this time into the total Election Day (900 minutes) and determines what it calls the "maximum daily rate". But voters do not arrive at the polling place in precisely evenly spaced intervals throughout the day. Peak voting times must be taken into account.

The AIR study results are therefore a large overestimate of the number of voters that can actually use any voting machine without creating long lines. More discussion of the limitations of the AIR study can be found in the NYVV's earlier submission, "Estimating the Number of Voting Machines for New York State's Polling Places" which is reproduced in the Appendix.[5]

Problems with the Board's Formula

The formula used by the State Board to determine the 550 voter per DRE number is simple but critically flawed. It compares the AIR study trimmed mean results of 337 voters per lever voting machine to the current New York State standard of 800 voters per lever machine, and determines a ratio from these numbers. It then takes the AIR trimmed mean results for each DRE in the study and applies the same ratio, which results in 550.

$$\frac{[\text{AIR report Lever Machine}]\ 337}{[\text{NYS Lever Machine Standard}]\ 800} = \frac{231\ [\text{AIR report DRE}]}{550\ [\text{Proposed DRE Standard}]}$$

The concept is that we know two things about lever machines: the number currently mandated by law, 800 registered voters per lever machine; and the AIR result, 337 voters per lever machine. The formula used by the Board attempts to normalize the AIR findings based on the legal and historical 800 registered voters per lever machine.

In essence the Board's formula says this: if the AIR study says a lever machine can serve 337 voters per day, and New York State says a lever machine can serve 800 voters per day, the AIR study results are off

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[2] DG Norris and CA Paulson, American Institutes for Research,
"New York State Voter System User Rate Assessment Study", 12/11/2006, 2006.
http://www.elections.state.ny.us/NYSBOE/hava/DRAFTAIRSTUDY.pdf 1/4/2007.

[3] It remains unclear why the State Board decided to leave the AIR study unfinished, particularly as the cost of the study was reported to be nearly $300,000! Why spend this much taxpayer money and then not require that the study be completed?

[4] On page 39 they say that these "estimates [for voters using disability aids] may be misleading" because they don't know if their sample is representative. In fact, they don't have any data on any correlation between the nature of the disability and the voting time.

[5] William A. Edelstein, Ph.D., New Yorkers for Verified Voting
"Estimating the Number of Voting Machines for New York State's Polling Places"
http://www.nyvv.org/newdoc/VotingMachineNumbersForNYS.pdf

by a factor of 2.75. We can then multiply the AIR results for other voting systems by the same factor to determine the actual number of voters that each of those systems can handle.

While appealing in its simplicity, this formula fails for a number of reasons:

1) As noted above the AIR study results are questionable and take no account of the crucial factor – number of voters arriving at peak voting times. As the well known computing phrase states, “Garbage in, garbage out”.
2) The Board’s formula assumes that the AIR lever machine results are off by a precisely measurable amount (in this case, 2.75), and that DRE results are off by exactly the same amount. But there is no basis for the assumption that a linear relationship exists between the data gathered for these vastly different voting machines.
3) Few if any New York State lever machines serve the full 800 voters allowed by law. Indeed, it is quite common, particularly in upstate New York, for there to be fewer than 600 registered voters assigned to each lever machine. The current state standard of 800 voters per lever machine is a legal standard that works out in practice because actual voter turnout is much lower than that. The actual number of voters served by a voting machine on Election Day is a practical standard. The Board is using *a legal standard* where *a practical standard* is required.
4) The formula compares apples to oranges. It assumes that voting on a lever machine is identical to voting on a DRE, but this is clearly not the case. Among other tasks not found on mechanical lever machines - DREs require voters to verify the printed VVPAT, verify an electronic review screen, adjust screen factors (font size, color, language), and possibly use accessibility features.

2) Analysis of the Actual Ratio of Voters per DRE Using Queuing Theory

If simplistic formulas cannot provide the answer, how then do we arrive at a reasonable standard for the minimum number of voting machines?

In November 2006 New Yorkers for Verified Voting submitted “New Voting Systems for New York – Long Lines and High Cost.”[6] Author William Edelstein used computer simulations and the mathematics of queuing theory to calculate the effects of higher voter arrival rates during peak voting times. Queuing theory is the mathematical study of waiting lines:

> “The theory permits the derivation and calculation of several performance measures including the average waiting time in the queue or the system, the expected number waiting or receiving service and the probability of encountering the system in certain states, such as empty, full, having an available server or having to wait a certain time to be served.
>
> Queuing theory is generally considered a branch of operations research because the results are often used when making business decisions about the resources needed to provide service. It is applicable in a wide variety of situations that may be encountered in business, commerce, industry, public service and engineering. Applications are frequently encountered in customer service situations as well as transport and telecommunication…”[7]

As can be seen, queuing theory is the methodology best suited to predict the effects of high voter arrival times during peak voting hours. In his analysis Dr. Edelstein notes:

> “Queuing theory in this case uses voter arrival rate, the number of available machines, the time for each voter to vote and the machine breakdown rate to predict the probability of forming long lines during Election Day and overtime at the end of the day.”

When we account for the effects of peak voting periods our computer simulations predict that New York’s DRE to voter ratio must be set no higher than 200 voters per DRE. This is over 2.5 times less than the Board of Elections proposed 550 voters!

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[6] William A. Edelstein, Ph.D., New Yorkers for Verified Voting
“New Voting Systems for New York – Long Lines and High Cost”
http://www.nyvv.org/doc/voterlines.pdf

[7] http://en.wikipedia.org/wiki/Queueing_theory

The NYVV queuing theory analysis makes clear that it is critical that peak voting times and voter arrival rates be considered if unacceptably long voter waiting times are to be prevented. And as will be seen in the following sections, data collected from a New York county and other states confirm that 200 voters per DRE is indeed the only reasonable standard.

3) The Columbia County Study of Voter Arrival Times in the 2006 General Election

Computer simulations are good for making predictions, but we must have confirmation from the real world in order to have confidence that the simulations accurately reflect reality. In the November General Election of 2006 the Columbia County Board of Elections undertook a study [8] to determine how many voters could be expected during peak times. The study was released in April 2007 and sent to all county election commissioners and the State Board of Elections. The Columbia County study independently confirmed the predictions of the queuing simulations which NYVV had submitted to the State Board of Elections.

The methodology used was simple. Commissioner Ken Dow explains:

> "In order to measure actual voter flow, we asked our inspectors to count and record the number of voters who arrived at each polling place during each 2-hour interval throughout the day at the 2006 General Election. We got data from 56 of our 58 Election Districts."

The Columbia County study is the only New York Board of Elections at the state or county level to gather concrete data on voter arrival rates during an actual election. The comprehensive data is assembled into a spreadsheet showing voter arrival rates for each two hour period and uses the data to make projections about waiting times and the numbers of machines required to handle peak voting times. [9] The data show some important facts about voter arrival times [*emphasis added*]:

> "*The most important information we learned is that during the 15-hour General Election, between 20 and 25 percent of all voters typically went to the polling place during the peak 2-hour period. A* second important finding was that the results from the different polling places were very consistent with each other. In the great majority of polling places, the peak period was between 4:00 and 6:00 PM. In several polling places the busiest time was between 8:00 and 10:00 AM, and a few polling places peaked at other times."

In an important corroboration of the NYVV analysis cited in the last section the Columbia County study showed the queuing theory prediction of 28 voters per hour at peak voting times was on average, exactly correct.

The results of the Columbia County study give further weight to NYVV's assertion that more than 200 voters per DRE will result in lines, long waits, and voter disenfranchisement. Further evidence supporting our analysis is the experience and practice of other states that have used DREs for years.

4) Voter to DRE ratios used by other states

Since many states have already begun using DREs, it is worth inquiring what voter to machine ratios are being used elsewhere. In May 2007 New Yorkers for Verified Voting submitted to the State Board of Elections a survey of other states titled "Survey Data on the Number of Voters per DRE in Other State Jurisdictions."[10] Author Marge Acosta notes:

> "Jurisdictions in DRE states report problems with long lines, even those using far fewer voters per DRE than the New York State proposal. In order to get some guidance from the practices of other states already using DREs, I contacted election officials in six jurisdictions – Lincoln, Tennessee; Cheyenne, Colorado; Carson City, Nevada; Esmeralda, Nevada; Clark, Nevada; and Palm Beach, Florida – to determine what ratios of registered voters to DREs they use, the length of time spent waiting in lines at the polls, and other relevant data."

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[8] "Study of Voter Flow at the 2006 General Election, Columbia County, NY"
Ken Dow, Commissioner of Elections, Columbia County
http://www.nyvv.org/newdoc/county/StudyOfVoterFlowAtThe2006GeneralElection04-27.pdf

[9] http://www.nyvv.org/newdoc/county/VoterFlowStudy2006GE-Final.xls

[10] "Survey Data on the Number of Voters per DRE in Other State Jurisdictions"
Marge Acosta, NYVV Long Island Representative
http://www.nyvv.org/newdoc/StateTimingData.pdf

Once again, the survey results confirm both the queuing theory analysis and the Columbia County voter arrival rate study. Of the six jurisdictions surveyed, 5 used voter to DRE ratios of less than 213 per voter, with one as low as 74. The sole outlier was Lincoln, Tennessee which used a standard of 328 voters, still 222 less than the New York State Boards proposal of 550 voters per DRE!

The usage data is compelling as observed in the following table from the study:

County and State	Registered Voters	Vendor and DRE	VVPAT	Average Number of Registered Voters per DRE
Lincoln, TN	18,000	ES&S iVotronic	No	328
Cheyenne, CO	1277	Hart eSlate	Yes	213
Carson City, NV	25,000	Sequoia AVC Edge	Yes	184
Clark, NV	803,808	Sequoia Edge II	Yes	179
Esmeralda, NV	667	Sequoia Edge	Yes	74
Palm Beach, FL	779,748	Sequoia Edge	No	175

Again we see data consistent with the idea that New York State must set the minimum number of voting machines to be no more than 200 voters for DRE systems.

5) Conclusions

Consider the consequences of assigning too many voters to a DRE voting machine. At the peak hours in the morning and evening rush, lines begin to form early and quickly get longer and longer. Voters become increasingly agitated as the waiting times go past a half hour to an hour, then an hour and a half. Machine breakdowns, all too common with DREs, cause further delays and force voters who have already waited too long to the back of other lines. Many who have come to vote can wait no longer and must return to pick up children or go to work, leaving the line angry that they have been denied their right to vote by an insufficient supply of machines. The results of the election are called into question, and the candidates and parties mount legal challenges which may keep the election undecided for months.

This doesn't have to happen. But if the New York State Board of Elections adopts the current proposal of 550 voters per DRE, it inevitably will. As demonstrated in this report, the formula used to determine the Board proposal is fatally flawed, a simplistic formulation using uncertain data and erroneous assumptions to arrive at an unjustifiable conclusion.

On the other hand, computer simulations based on mathematical models of waiting lines and real world data from a New York county and other states around the nation show that no more than 200 voters should be assigned to each DRE. The theory predicts it, and the real world data confirms it. There can be no mistake.

If the State Board of Elections gets this decision wrong it will be responsible for what will be seen as the worst disaster in New York State voting history. The evidence is clear and there is no room for error. It now falls to the New York State Board of Elections to evaluate the data, reject simplistic answers, and require an ample number of voting machines in each polling place. If they get it wrong in spite of the compelling evidence, they will have to answer to the public, and to history.

Appendix A

Previous Submissions to the New York State Board of Elections and Supplemental Materials

As noted in the text, New Yorkers for Verified Voting (NYVV) has made several earlier submissions to the Board on the subject of the minimum numbers of voting machines. These earlier submissions are included again as part of this paper on the following pages.

This document with the full text of all submitted reports and supplementary material is available for download here:

http://www.nyvv.org/newdoc/NYVVMinNumberVotingMachines091507FULL.pdf

Below is a list of online links to the following documents.

1) NYVV Submission to the New York State Board of Elections November 2006
William A. Edelstein, Ph.D., New Yorkers for Verified Voting
"New Voting Systems for New York – Long Lines and High Cost"

http://www.nyvv.org/doc/voterlines.pdf

2) NYVV Submission to the New York State Board of Elections January 2007
William A. Edelstein, Ph.D., New Yorkers for Verified Voting
"Estimating the Number of Voting Machines for New York State's Polling Places"

http://www.nyvv.org/newdoc/VotingMachineNumbersForNYS.pdf

3) NYVV Submission to the New York State Board of Elections March 2007
"New York State BOE Proposal for Numbers of Voters per Machine Guarantees Long Lines and Voter Disenfranchisement"

http://www.nyvv.org/doc/Resp070326.pdf

4) NYVV Submission to the New York State Board of Elections May 2007
"Survey Data on the Number of Voters per DRE in Other State Jurisdictions"
Marge Acosta, NYVV Long Island Representative

http://www.nyvv.org/newdoc/StateTimingData.pdf

5) Columbia County Board of Elections Study May 2007
"Study of Voter Flow at the 2006 General Election, Columbia County, NY"
Ken Dow, Commissioner of Elections, Columbia County

http://www.nyvv.org/newdoc/county/StudyOfVoterFlowAtThe2006GeneralElection04-27.pdf

http://www.nyvv.org/newdoc/county/VoterFlowStudy2006GE-Final.xls

Appendix B

NYVV Submission to the New York State Board of Elections November 2006

William A. Edelstein, Ph.D., New Yorkers for Verified Voting
"New Voting Systems for New York – Long Lines and High Cost"

http://www.nyvv.org/doc/voterlines.pdf

New Voting Systems for NY—
Long Lines and High Cost

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November 14, 2006

New Yorkers for Verified Voting

New Voting Systems for NY—Long Lines and High Cost

William A. Edelstein, Ph.D.*

November 14, 2006

As New York decides on new voting systems, one key question is this — how many voters can be served by each voting machine? This number is critical in order to estimate costs as well as to avoid long lines for voters. The New York City Board of Elections recently released a report saying that New York should replace each lever machine by 1 full-face-ballot computer DRE voting machine with voter verified paper trail. Assuming that each voter will take 3.25 minutes to vote, they calculate that 277 voters can vote on each DRE in a 15-hour Election Day. However, the report neglects the effect of non-uniform voter arrivals, DRE outages and extra time needed by voters using special accessibility aids on DREs. We have applied queuing theory, the mathematical study of waiting lines, to carry out computer simulations of realistic elections. We use a scenario with more voters arriving at peak times—early morning, lunch and early evening hours—as is typical during elections. According to our calculations, a ratio of 277 voters per DRE would create unacceptable wait times of 1 hour or longer. Recent elections using DREs have produced extremely long lines in many places around the country, causing would-be voters to leave, thereby disenfranchising them. In order to guarantee reasonably short wait times—even without taking into account DRE outages and the use of DRE special voting aids—our results indicate that each DRE in New York should be allocated to no more than 150 voters, which means replacing each lever machine by 3 DREs. But the acquisition and maintenance cost of this many electronic voting machines would be excessive. In contrast, precinct based, paper ballot optical scan systems use simple, inexpensive marking booths that are the equivalent choke points to DREs. These paper ballot scan systems can be easily and economically configured to eliminate lines.

Voting system choice: timing is everything

Early next year, New York counties will choose either direct recording electronic voting machines (DREs) or paper ballot-scanner systems (PBOS) to replace lever voting machines. How many new voting machines will be needed? The answer to this question is critical for ensuring that each county's voting will go smoothly and that costs will be within reason.

Long lines have occurred during elections with DRE use in California, Florida, Maryland, Mississippi, Ohio, Pennsylvania, Tennessee, Utah and other states[1-9] and have caused some voters to give up and go home, effectively disenfranchising them. It is prohibitive to buy a large number of DREs because of their cost, which makes it likely that a substantial number of voters using DREs will end up in long lines. In contrast, PBOS uses inexpensive marking booths whose numbers can be increased to eliminate lines and long waits.

The New York City Board of Elections recently published a report entitled "An Analysis of the Number of Voters per Voting Machine"[10] which omits several important considerations and contains a number of doubtful assumptions. The result is a serious underestimate of the number of DREs that would be needed to serve the voters of New York City as well as a misunderstanding of relevant aspects of paper ballot-scanner systems.

The New York City Board of Elections report:

- Incorrectly assumes that a maximum of 50% of voters will appear at any election;
- Does not take into account the extra time needed to vote on DREs by persons with disabilities;
- Does not take into consideration the uneven arrival of voters, particularly during peak voting hours, and potential voter traffic jams;
- Does not include the effects of machine and procedural breakdowns.

Properly taking these factors into account substantially decreases the number of voters that could use a voting machine in a day and considerably increases the number of DREs that would have to be purchased and maintained.

In their examination of the use of DREs in the recent Cuyahoga, OH primary, the Election Science Institute carried out a queuing theory analysis of the potential for long lines.[11] Following their approach, we have done our own queuing theory simulation of voting statistics. If we accept the NYC Board of Election report's figure of 3.25 minutes to vote on a DRE with voter verifiable paper trail—which the report claims will allow 277 voters to use a single machine in a 15-hour voting day—then our study shows that a significant fraction of such elections will have maximum voter waits of over an hour to cast their ballot. This will happen even without the all too common experience of DRE breakdown; it also will occur even if we do not factor in extra time for voters with disabilities. Details of our calculations are given in the Technical Appendix.

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The only way to guarantee short lines is to have a large overcapacity, i.e., to have many more voting systems than would be needed for the average voter flow. This is not practical with DREs because of their high cost. However, New York counties could avoid long lines and save money by choosing paper ballot scanner systems. In the 2004 general election, Lee, MA accommodated 3200 voters on a single paper ballot scanner[12] and Londonderry, NH[13] processed more than 12,000 voters on two scanners in a 13-hour Election Day. Voters mark their ballots in inexpensive marking booths, and there were no lines waiting to mark ballots or to use the scanners in these towns. The number of marking booths can be increased at low cost to avoid any problems of voter traffic congestion and long lines.

Factors not fully considered by the NYC report

Voter turnout will be significantly higher than 50% at some pollsites

The NYC report[10] assumes that a maximum of 50% of registered voters will appear in any election and calculates the number of machines they will order based on this assumption. While the average turnout for New York's 5 counties (New York, Bronx, Kings, Queens and Richmond) was indeed 50% in the 2004 general election, many areas had higher figures.[14,15] So to guarantee efficient access to the polls, it is necessary to consider the peak vote, which could occur in any election precinct.

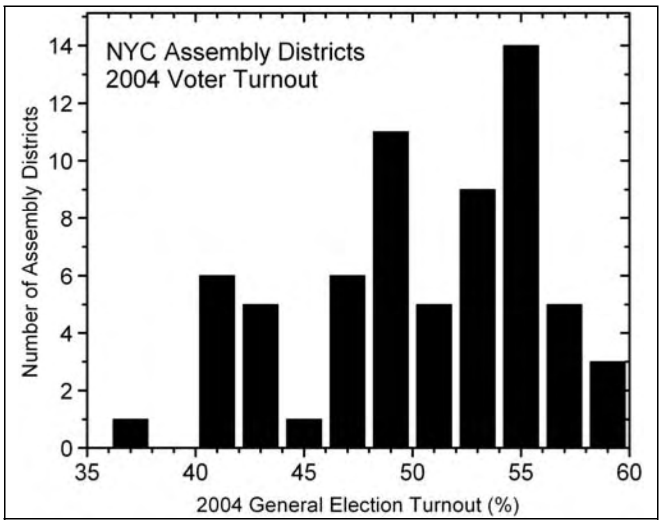

Figure 1. Number of New York City Assembly Districts vs. % turnout in the 2004 general election. Each bar represents how many Assembly Districts had turnout in the range covered by the bar. There were 6 districts that had turnout between 40%-42%, 5 districts had turnout between 42%-44%, 1 district between 44%-46%, etc.

Figure 1 shows the number of Assembly Districts in New York City Counties vs. their votes for President in the 2004 election.[14,15] There are many Assembly Districts where the turnout was well above 50%, indeed approaching 60%. Since these are averages over Assembly Districts, it is apparent that some election precincts within these Districts must have had higher turnouts than 60%. Statewide, over 60% of voters showed up. (The Lee, MA and Londonderry, NH examples cited above had over 80% turnout in 2004.)

The 2004 NY data suggests that an estimate of 75% as an upper bound for voter turnout would be appropriate. This is the same percentage that has been used by NYC to determine how many lever voting machines should be deployed. An underestimate of the number of machines could lead, at least, to serious voter traffic flow problems, long waits and extended Election Days. At worst, it can lead to voter disenfranchisement.

This occurred in the 2004 general election in Florida and Mississippi.[1,2] In Ohio long lines caused voters to give up and leave without voting.[4] There were more long lines in the recent 2006 primary in Cuyahoga County, OH.[11] There were long lines—along with other DRE issues—in the September 2006 problematic primary in Maryland.[3] Insufficient DREs and DRE malfunctions caused more long lines and voter frustration in a number of places in this year's general election on November 7 (e.g. refs. 5-9).

People with special needs will take much longer than 3.25 minutes to vote on DREs

The New York State Board of Elections studied the time needed for persons with special needs to vote with ballot marking devices.[16] This varied from 18 to 45 minutes among the several systems and types of accessibility aids considered. Voting on DREs using accessibility aids would be similar.

The New York State Board of Elections (NYBOE) has hired the American Institutes for Research (AIR)[17] to test voting machines and answers are supposed to be coming in the next few months. Part of their charge is to estimate how many voters would use accessibility aids. This would include, for example, voters with visual, dexterity, or mobility impairments who would use the audio interface or sip and puff controls. It might also include voters who are not comfortable with computers, touchscreens, or the use of English.

A small number of voters with special needs, each taking 30 minutes to vote, would have a profound effect on numbers of voters able to use a DRE on Election Day.

Voters do not arrive at exact intervals

The NYC report allots an average of 3.25 minutes for each voter to use a DRE with voter verifiable paper record. 900 minutes (a 15 hour Election Day) divided by 3.25 is 277. They then assert that a single DRE can accommodate 277 voters, and propose to buy one DRE for each 554 registered voters on the basis of a 50% turnout. However, the NYC report does not properly take into account the effect of fluctuations of voter arrival. It says[10]

> On Election Day, there are "peaks and valleys" of usage by voters depending upon the time of day, the weather, traffic and other variables outside of the control of election staff. Thus there will always be times when voters are waiting, but on the whole, there should be some insurance that waits will not be over long durations throughout the day and that on the whole, voting can be accomplished expeditiously. If we make the assumption that on the whole elections are conducted expeditiously by the survey jurisdictions, than [sic] a maximum that is at, or somewhat higher

than, the average by type of technology should be a reasonable maximum for New York.

These unsupported assumptions are contradicted by DRE delays around the country[1-9] and the mathematics of queuing theory that governs the voting process.

We begin our election simulation by assuming 277 voters per DRE estimated by the NYC report. We take a scenario with heavy voter arrivals from 6am to 8am, 12pm to 1pm and 5pm to 7pm, where voters arrive at double the rate of the rest of the day, and no DREs break down. If the whole-day average is 18.5 arrivals per hour, then the slow periods will have 14 per hour and the fast periods 28 per hour.

There will be many voting locations where only a small number of DREs will be needed,[10] so we have focused—as examples—on pollsites with 1, 2 or 4 DREs. Sites with more DREs will behave proportionally.

With these conditions, over 80% of precincts with 1, 2 or 4 DREs will have voters waiting for more than an hour. Voters will have a maximum wait of more than 1-1/2 hours in 38%, 17% and 3% of precincts where there are 1, 2 or 4 DREs, respectively.

If we have 150 voters per DRE—approximately the ratio of privacy booths to voters specified by statute in NH, scaled by the different Election Day lengths in NH (13 hours) and NY (15 hours)—then there will be few voters waiting more than thirty minutes.

DREs and printers will break, need rebooting, or otherwise cause delays

DRE outages will cause further delays. The present reliability guidelines allow over 9% of voting machines to fail in a 15-hour day,[18] and ESI uses a one-hour average repair/replacement time in some of their calculations.[11]

The bottom line is that even with many more DREs than recommended by the NYC report,[10] queuing statistics guarantee that a substantial number of voting precincts will have voters with very long waits. In order to avoid long lines at DREs for all precincts, it is necessary to have a large excess capacity of voting machines. With DREs, this is not realistic because of their high acquisition and operating costs.

Paper Ballot/Optical Scan: Londonderry, NH and Lee, MA

The following examples of voting by paper ballots and ballot scanners show how PBOS systems can eliminate long voter queues at a minimal cost.

Lee, MA uses PBOS. They had 4,000 registered voters and 3,200 (80%) used 35 privacy booths and one scanner in the 2004 election. The Lee town clerk says that they had no lines at the privacy booths in the 2004 election, whereas they had "long, long lines" when they had previously used 8 lever machines.[12]

Londonderry, NH has 15,029 registered voters and 12,229 (81%) of them voted in the 2004 election.[13] They use PBOS and have two scanners. Each scanner therefore processed about 6114 ballots which is equivalent to 7055 ballots in a 15-hour day. (Note--even if we changed this by a factor of two to accommodate undervote notification in NY, each scanner could still handle 3527 ballots in a day.)

Londonderry has 100 privacy booths, each of which served an average of 122 people in their 13 hour Election Day in 2004, equivalent to 141 voters per NY's 15 hour Election Day. The town clerk said that there were no lines at the privacy booths. NH requires a privacy booth for every 125 voters. Just in case more voters show up, she has extra cardboard privacy screens that can be placed on tables.

During a heavy election, the Londonderry town clerk estimates that only 10% of booths will be filled much of the day but 90% are occupied during peak times.

Since the scanners only count ballots but do not record the votes, a stopped scanner does not halt the election, unlike DRE failures. If the scanner is down, the ballots are placed in a special compartment in the ballot bin and scanned later. The Londonderry town clerk has supervised 25-50 elections over the last 7 years and has experienced only one scanner breakdown. A replacement scanner was brought over and put into service in less than an hour.

These examples show the kind of overcapacity that works. It is easy to achieve with PBOS since the privacy booths cost about $150 each. In reality, it would take more than 100 DREs in Londonderry, NH or 35 DREs in Lee, MA to achieve the same ease of use since 1) DREs have a much greater breakdown rate than scanners and 2) voters with disabilities would take up a lot of DRE capacity. In contrast, ballot-marking machines that go with PBOS are separate devices that do not affect flow of voters in other privacy booths or the operation of the scanners.

How many voting machines do we need?

Direct Recording Electronic Voting Machines (DREs)

The NYC report suggests that each DRE could serve 277 voters on Election Day. Assuming a 50% turnout, they conclude that one DRE should be purchased for each 554 registered voters, which is not too different from what the report says is an average of 1 lever machine for 600 registered voters. In other words, they recommend replacing each lever machine by a single DRE.[10]

Our study shows that 277 voters per machine is unrealistic (given the NYC voting time figure of 3.25 minutes) and will lead to very long waiting times in some election districts. We believe a realistic ratio that keeps lines down everywhere would be more like 150 voters per DRE. Trying to serve even this number of voters with one DRE may prove problematic because of DRE outages and long voting times for persons with special needs. Taking 150 voters per DRE and a possible 75% turnout implies a DRE for each 200 registered voters. The replacement ratio then becomes 3 DREs for each lever machine.

The time for each person to vote (3.25 minutes) in our calculation was taken from the NYC report and could change when the "usability study" is completed by AIR. Any figures then obtained can—and should—be used for a queuing analysis similar to what we have done here.

Paper Ballot, Ballot Marker, Optical Scan Systems (PBOS)

The examples above from Londonderry, NH and Lee, MA demonstrate that a large overcapacity, i.e. one privacy booth for 125 voters (Londonderry, NH) or per 90 voters (Lee, MA) essentially eliminated the experience of voting bottlenecks. This is a simple and inexpensive solution which would improve the voting experience in New York, as it did when Lee, MA went from 8 lever machines for 3200 people to 35 privacy booths.

If we scale the NH number from a 13 hour day to a 15 hour day, then one needs approximately one privacy booth for each 150 voters who show up. Assuming a 75% turnout, we therefore need a privacy booth for each 200 registered voters. As is done by the Londonderry, NH town clerk, it is a good idea to have a number of additional folding cardboard privacy screens that can be placed on tables in case more voters come.

As mentioned above, ballot marking devices that would be used by voters with disabilities will not affect the voting process for other voters. With this option, election commissioners have to determine how many disabled voters will vote in their election district and buy enough ballot marking devices to serve their disabled constituents. Commissioners should be aware that as voters with disabilities become more familiar with new voting technology, their attendance at polling sites will increase..

Acquisition Costs

A simple calculation for a pollsite with 2,000 registered voters shows how PBOS could save $45,500 in acquisition costs compared to buying DREs.

According to our figures above, this pollsite would require 10 DREs at approximately $8,000 each or $80,000.

The same pollsite could be served by a single optical scanner ($5,500) and 10 marking booths ($150 each, $1,500). It would also need ballot marking devices for the disabled.

We now calculate the number of ballot marking devices needed. Let us assume a 75% turnout (1,500 voters), that 5% of those voters (75) need special access and that each takes 30 minutes. 900 minutes divided by 30 minutes is 30. There will be a similar queuing problem for the ballot markers as there was for the DREs, so that number should probably be decreased by a factor of 2 to 15. Then the district should buy 5 ballot marking devices at about $5,500 each which comes to a total of $27,500.

Thus the total is $5,500 + $1,500 + $27,500 = $34,500 for PBOS and ballot marking device acquisition costs, $45,500 less than the figure for DREs.

Conclusions: DREs will cause long lines; PBOS can eliminate lines

The use of DREs has created long lines in many constituencies around the country. The nature of voter arrival statistics is such that there may be a large variability in the waiting times for different voting locations as governed by the mathematics of queuing theory. The only way to avoid long waiting times for voters is to have a large overcapacity, i.e. many DREs or many marking booths for use with PBOS. This is only economically possible with PBOS, as DREs ($8,000) represent the equivalent choke point in the voting process as the marking booth ($150).

DRE outages (10% in recent experience) and long voting times for persons with special needs represent further potential serious slowdowns on Election Day.

We believe that 30 minutes should be the maximum waiting time for voters. Many of them may be taking time off work, have to manage accompanying children or have medical conditions that make it difficult for them to stay at the polling place for extended times. Every precinct that follows the advice of the New York City Report to allocate one DRE for each 277 actual voters will exceed that standard. Most will have maximum wait times of at least one hour, and a significant number will have wait times greater than 1-1/2 hours.

Recent experience shows that such a result produces frustration or hardship for voters and many will leave rather than wait in long times. The analysis in the Technical Appendix shows that numerous polling places allocating 1 DRE for each 277 voters will also have substantial overtimes, creating long workdays for election workers. 150 voters per DRE might work reasonably well, although the picture is clouded by DRE breakdown and use by disabled voters.

These numbers are similar to those in a story about a voting precinct with 2 DREs in Nashville, TN. Elections went well with 214 voters (107 per DRE) but had long lines with 527 voters (263 per DRE).[5]

The correct and smooth functioning of elections is fundamental to democracy. Everything compatible with election integrity should be done to make the process voter-friendly—overlong waits are unacceptable. If a city has hundreds of precincts and ten of them have multi-hour waiting lines or Election Day delays which force voters to continue well beyond midnight—as happened in Ohio in 2004—voters will blame election commissioners and other government officials for not having enough machines. People will leave without voting; this amounts to disenfranchisement of those voters. There will be angry charges that the election has been compromised or manipulated.

The uneven flow of voters on Election Day means that the only way to guarantee equal voter access in terms of the time it take to vote is to have a sizable overcapacity in every district. Both acquisition and operating costs make that economically prohibitive with DREs. More machines mean higher operating costs as well as higher acquisition costs. To provide for reasonable waiting times, it will be necessary to have three times as many DREs as the NYC Board of Election suggests. In contrast, it is eminently feasible to have negligible lines for PBOS systems, because it is possible to supply a large number of inexpensive privacy booths for marking ballots.

Technical Appendix: Queuing Theory, Voter/Voting Machine Ratios, and Long Lines

"Queuing theory…is the mathematical study of waiting lines."[19] We are concerned here with lines of people waiting to use voting machines. Queuing theory in this case uses voter arrival rate, the number of available machines, the time for each voter to vote and the machine breakdown rate to predict the probability of forming long lines during Election Day and overtime at the end of the day. We have applied this approach to a few simple scenarios to show that the numbers of DRE machines proposed by the NYC report would lead to long lines, many with delays of one to two hours or even longer.

The NYC report starts its calculations with the premise that each voter will take approximately 3.25 minutes to vote on a DRE with a voter verifiable paper trail. They then divide a 15-hour voting day (900 minutes) by 3.25 minutes and conclude that 277 people can all vote on a single machine in one day, or, conversely, that it is only necessary to buy one DRE for every 277 actual voters.

This might be OK if people were to arrive precisely every 3.25 minutes like clockwork. In reality, they come to the polls randomly according to a Poisson process with an exponential distribution of intervals between arrivals.[20] Sometimes they drop in more frequently than the average rate and have to wait. Sometimes they show up more slowly and machines sit idle, wasting time that cannot be made up and that inevitably lead to lines or overtime at the end of the day.

More voters come early in the morning, at lunch or after work and during the dinner hour than during the rest of the day. The NYC estimate does not take this into account. Neither does it factor into its analysis DRE outages that occur with a 10% probability and take an average of one hour to repair. In addition, it does not include the fact that persons with disabilities will use special functionalities of the DREs and take extra time to vote.

Our calculations were based on the use of 1, 2 or 4 DREs, as there will be many pollsites with a small number of DREs.[10] Larger sites would operate proportionately.

Queuing calculations: methodology

Based on references 11 and 21, we wrote a computer program to simulate voting during a 15-hour Election Day, from 6am to 9pm. From 6am to 8am, 12pm to 1pm, and 5pm to 7pm the arrival rate was double that for the rest of the day. We carried out calculations for 1, 2 or 4 DREs in a pollsite under the following conditions.

1. An average of 277 voters per DRE as estimated by the NYC Board of Elections;
2. An average of 150 voters per DRE, approximately the equivalent to the requirement of 125 privacy booths for PBOS in NH for a 13-hour Election Day.
3. The effect of DRE outages for 150 voters per DRE;
4. The effect of disabled voters and voters with other special needs who take 30 minutes each to vote.

Calculations for DREs without factoring in outages or voters with special needs

Two exponential distribution sets of random arrival intervals are generated, one for most of the day and another for the higher rate between 6-8am, 12-1pm and 5-7pm. Each voter is then assigned to the machine which has finished (or will finish) earliest with previous voters. If the machine is available, then that machine is occupied for 3.25 minutes. If the machine is not yet free, the voter waits for it to be available and then takes 3.25 minutes to finish. In some cases the voter may arrive well after one of the machines has been free.

We calculated the case for 150 voters per DRE first without, and later with, DRE outages.

Maximum waiting times and waiting time for the last voter (overtime) are then extracted from the results. Each simulation for 1, 2 or 4 DREs is repeated 10,000 times to get a statistical distribution of maximum waiting times and overtimes.

Figure A1 shows a waiting pattern for 2 DREs. Taking the NYC suggested number of 277 voters per DRE in the day, long lines develop during and following higher arrival rates at 6-8am, 12-1pm and 5-7pm. In this example, voters around 8am are waiting 80 minutes, and there is a 20 minute overtime at the end of the day.

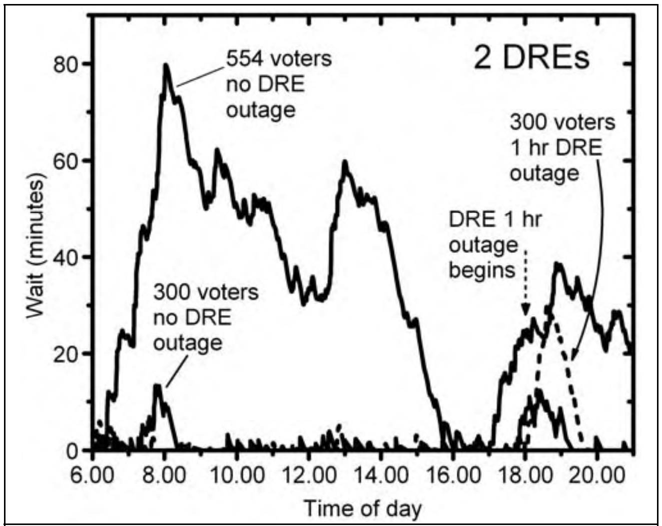

Figure A1. Typical waiting patterns for a 2 DRE precinct. In the scenario for the NYC figure of 277 voters per DRE (554 total), voters arrive every 1 minute during 6-8am, 12-1pm and 5-7pm, and 1 every 2 minutes during the rest of the day. For 150 voters, the corresponding figures are 1.9 and 3.8 minutes. Voter waiting times are shown for: a total of 554 voters (277 voters per DRE); 300 voters (150 voters per DRE); and 300 voters where one DRE has a 1-hour outage. The 554 voter example has extensive waiting times set off by the high turnouts during morning, lunch and evening.

For 150 voters per DRE (total 300), the longest waiting time is about 10 minutes. The DRE outage occurring around 6pm produces a 30 minute maximum wait.

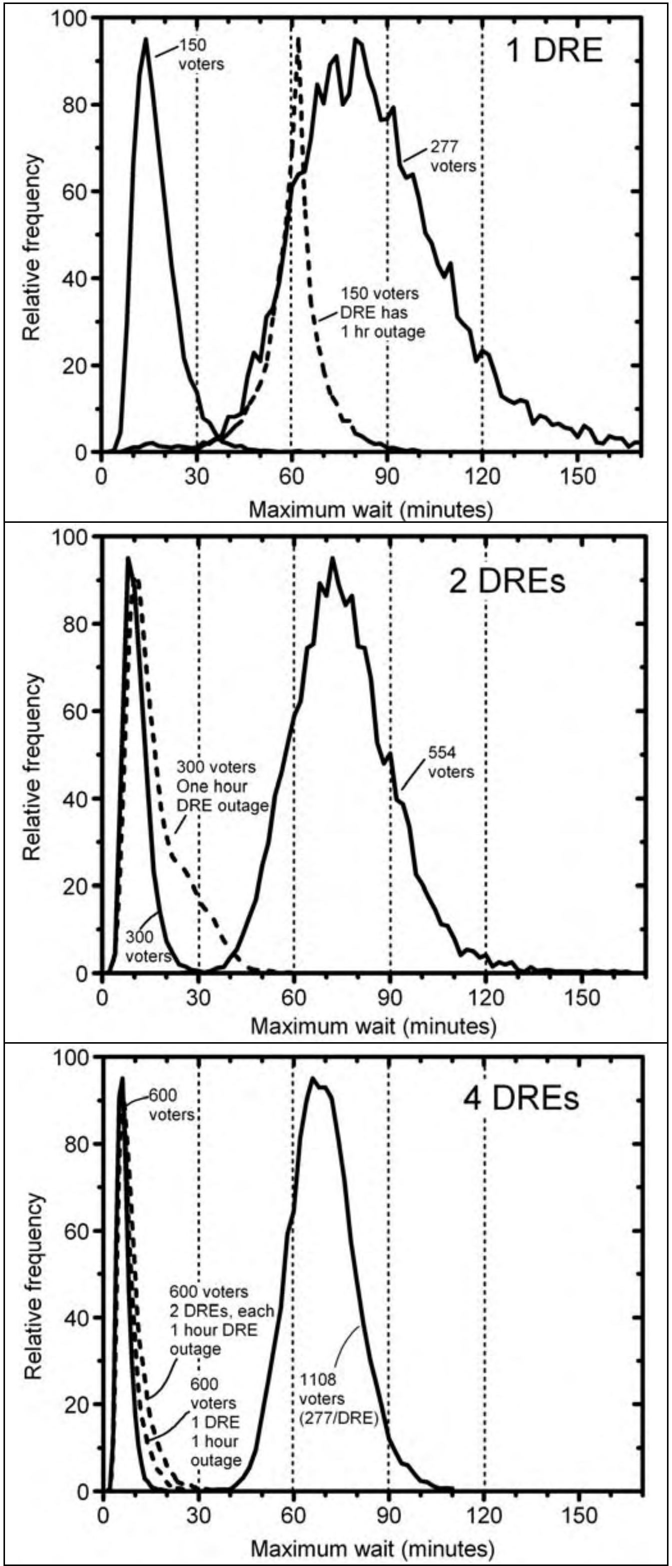

Figure A2. Distribution of maximum waiting times for voting precincts with 1, 2 or 4 DREs. Curves are shown for an average of 277 voters per DRE and for 150 voters per DRE. The results for 150 voters per DRE with 1-hour DRE outages are also displayed. The curves are histograms derived from runs of 10,000 simulations, and heights have been normalized in order to make comparison easier.

Figure A2 shows a distribution of maximum waiting times for 1, 2 and 4 DREs for 277 voters per DRE and 150 voters per DRE. 277 voters per DRE results in long waits averaging 70-80 minutes. The distribution for 1 DRE is wide and there will be a significant number of people waiting more than 2 hours. The fraction of the time voters will have to wait more than 30, 60, 90 or 120 minutes is the integral of the curve to the right of each particular time.

Table A1 shows the results for precincts with 1, 2 and 4 DREs respectively for an average 277 voters per machine, no DRE outages. Table A2 shows the corresponding results for 150 voters per DRE.

Table A1. Maximum wait time and overtime for 277 voters per DRE, 15 hr Election Day from 7 am to 10 pm. Arrival rate twice as high from 6 am to 8 am, 12 pm to 1 pm, 5 pm to 7 pm, as rest of day. No DRE outages and no voting with disability aids.

Maximum wait						
# DREs	Avge # of voters	**Avge max wait (min)**	>30 min max wait	>60 min max wait	>90 min max wait	>120 min max wait
1	277	85.9	100.0%	88.3%	38.1%	8.4%
2	554	75.4	100.0%	83.6%	16.9%	1.2%
4	1108	69.2	100.0%	81.1%	3.3%	0.0%
Overtime						
		Avge over-time (min)	>30 min over-time	>60 min over-time	>90 minutes over-time	>120 min over-time
1	277	45.1	64.8%	29.1%	8.6%	2.0%
2	554	37.0	60.0%	14.2%	1.5%	0.5%
4	1108	33.2	56.8%	4.6%	0.4%	0.0%

Table A2. Maximum wait time and overtime for 150 voters per DRE, same conditions as Table A1.

Maximum wait						
# DREs	Avge # of voters	**Avge max wait (min)**	>30 min max wait	>60 min max wait	>90 min max wait	>120 min max wait
1	150	17.3	5.3%	0.0%	0.0%	0.0%
2	300	10.9	0.1%	0.0%	0.0%	0.0%
4	600	6.6	0%	0%	0%	0%
Overtime						
		Avge over-time (min)	>30 min over-time	>60 min over-time	>90 minutes over-time	>120 min over-time
1	150	1.1	0%	0%	0%	0%
2	300	0.3	0%	0%	0%	0%
4	600	0.1	0%	0%	0%	0%

Figure A2 also has plots showing the effect of DRE failure in polling places with 150 voters per DRE. Voter waits in a precinct with one DRE are seriously affected with maximum waits around one hour, as would be expected. The effects in 2-DRE or 4-DRE precincts are not a problem in this case. However, given the 10% failure rate of DREs, this result says that there should be no precincts with a single DRE, even if there are 150 voters or fewer.

These figures match well the experience of a 2-DRE voting precinct in Nashville, TN. An election with 214 voters (107 per DRE) went well. The 2006 general election had 527 voters (263 per DRE), 4-hour waits and an overtime of 5-1/2 hours. [5]

Voters with disabilities

The NY State Board of Elections tested ballot marking devices for the disabled and found that it took 18-45 minutes to vote. We have done voting day simulations assuming the average value 30 minutes for disabled voters and 3.25 minutes for non-disabled voters on DREs that are scheduled to serve about 150 voters each, the figure we estimate from PBOS usage. Even with only 150 voters per DRE, substantial delays will occur with a relatively small number of disabled voters.

Figure A3 is an example of waiting times for 4 DREs with a total of 20 disabled voters (out of 600 voters total) with their arrival times—determined by random numbers—shown in the graph. As discussed above, 4 DREs can handle 600 voters with essentially no waiting times. Figure A3 has a sizable number of disabled voters appearing at busy times. About 7 come between 5pm and 7pm, which causes a large accumulated delay.

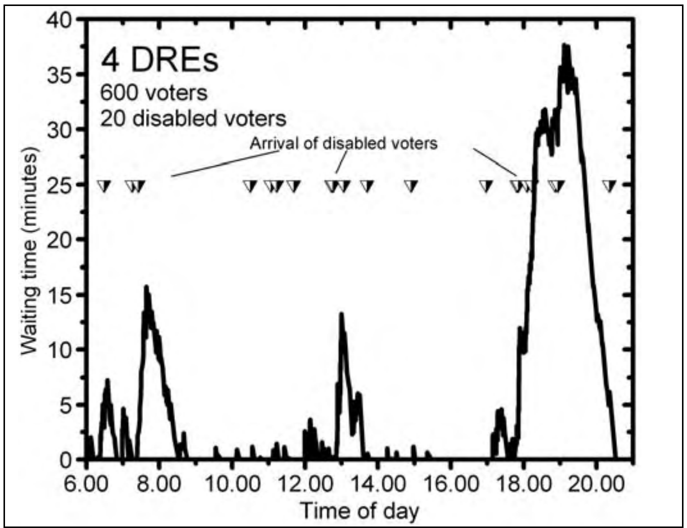

Figure A3. Waiting times for 4 DREs with 20 disabled voters arriving randomly throughout the day. The downward pointing triangles indicate the disabled voter arrival times.

Figure A4 shows distributions of maximum waits for 1, 2 and 4 DREs with 0, 2, 5 and 10 disabled voters per DRE (150 total voters per DRE). The distributions were derived by running 10,000 simulated elections for each case. The adverse effects decrease for more DREs. Increasing the number of DREs tends to smooth out the perturbations in produced by 30-minute voting periods.

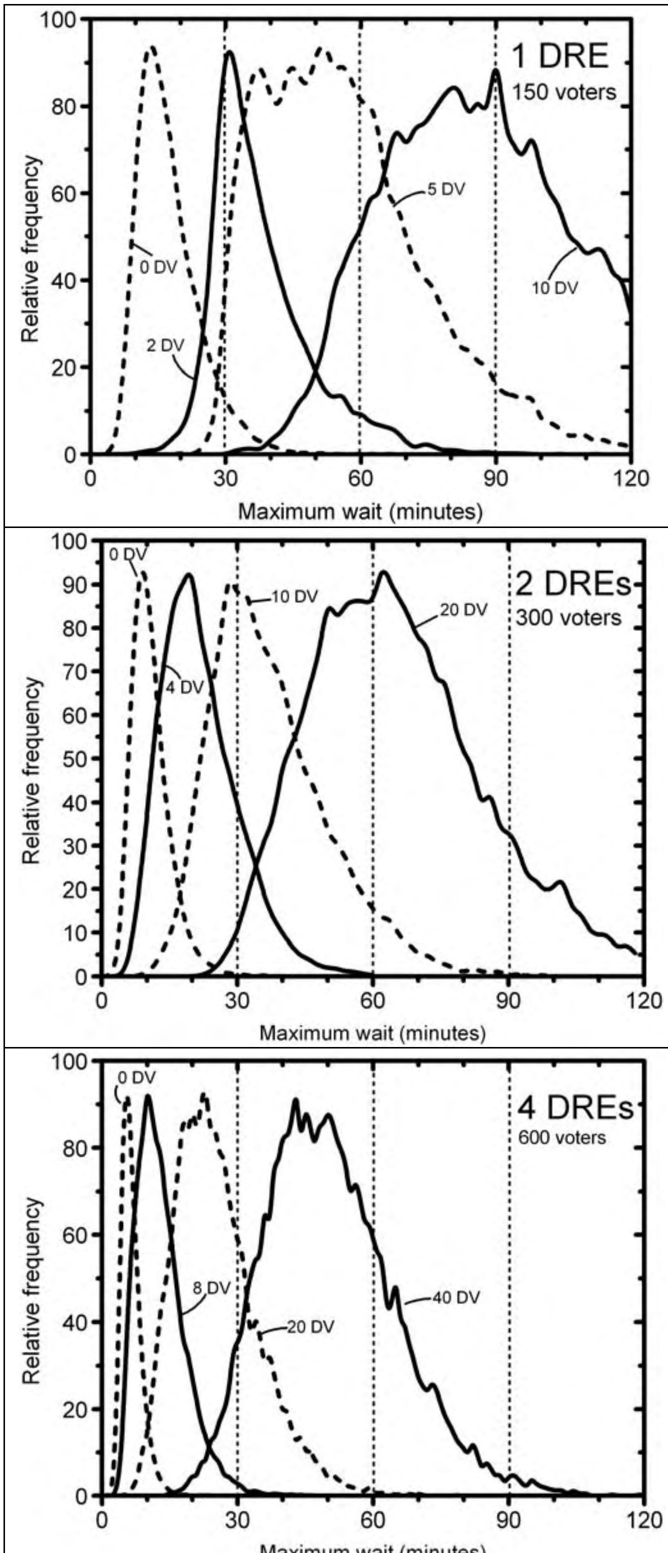

Figure A4. Distributions of maximum waiting times for DREs with disabled voters. The DREs average a total of 150 voters each. Simulations are shown for 0 disabled voters (0 DV), 2 DV, 5 DV and 10 DV per DRE. 10 DV/DRE is only 6.7% of the total 150 and 3.6% of the 277 voters per DRE suggested by the NYC Board of Elections. It is apparent that, for 1 DRE, a substantial number of voters will have waits of longer than 1 hour if either 5 or 10 disabled voters come to vote. 5 or 10 disabled voters per DRE will also cause long waits for a pollsite with 2 or 4 DREs.

Table A3 shows the maximum waiting times as a function of voters with disabilities for precincts of 1, 2 or 4 DREs. With only 2 such voters, 76% of the 1-DRE precinct will have greater than 30 minute maximum waits. With 10 voters with disabilities per DRE, over 90% of pollsites would have greater than 30 minute waits in every election. 1-, 2- and 4-DRE districts will have greater than 1 hour maximum waits 91%, 58% and 24%, respectively.

10 voters with disabilities per DRE is only 6.7% of the 150 voter figure or 3.6% of the 277 voters per DRE suggested by the New York City Board of Elections.

Table A3. Maximum waiting time for varying numbers of disabled voters (DV). 150 total voters per day per DRE with 0 DV/DRE, 2 DV/DRE, 5 DV/DRE and 10 DV/DRE.

	1 DRE	2 DREs	4 DREs
0 DV/DRE	**0 DV**	**0 DV**	**0 DV**
> 30 min	5.2%	0.2%	0.0%
> 60 min	0.0%	0.0%	0.0%
> 90 min	0.0%	0.0%	0.0%
> 120 min	0.0%	0.0%	0.0%
2 DV/DRE	**2 DV**	**4 DV**	**8 DV**
> 30 min	76.4%	16.5%	0.9%
> 60 min	5.1%	0.1%	0.0%
> 90 min	0.1%	0.0%	0.0%
> 120 min	0.0%	0.0%	0.0%
5 DV/DRE	**5 DV**	**10 DV**	**20 DV**
> 30 min	98.2%	67.1%	27.1%
> 60 min	37.6%	6.1%	0.2%
> 90 min	5.8%	0.1%	0.0%
> 120 min	0.6%	0.0%	0.0%
10 DV/DRE	**10 DV**	**20 DV**	**40 DV**
> 30 min	100.0%	99.3%	94.5%
> 60 min	90.6%	57.9%	24.1%
> 90 min	47.7%	12.3%	1.2%
> 120 min	15.2%	1.3%	0.0%

Figure A5 is a parametric plot of the fraction of elections with maximum waits of 30 or 60 minutes as a function of voters per DRE for pollsites with 1, 2 or 4 DREs. For example, 1% of the pollsites with 2 DRE will have waits of over 60 minutes if there are more than about 220 voters allocated to vote on that DRE.

Real conditions can vary, but we can use this plot and information derived above to develop a criterion for specifying the number of voters per DRE. We suggest a cutoff of 0.1% (1 in 1000 elections) for maximum waits over 30 minutes. This would allow 110 voters in 1 DRE polling places, 150 voters per DRE (280 voters) in 2 DRE pollsites, and 170 voters per DRE (680 voters) in 4 DRE pollsites. A reasonable average value drawn from these data would be 150 voters per DRE in all pollsites.

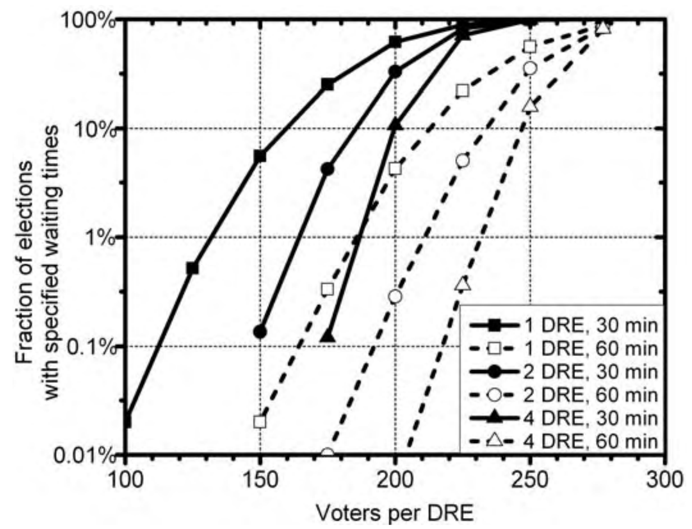

Figure A5. Fraction of elections with maximum waits of 30 minutes or 60 minutes vs. voters per DRE for 1, 2 or 4 DREs. To keep maximum waits below 30 minutes in 0.1% (1/1000) of elections, it would be necessary to have about 110 voters for 1 DRE, 140 voters per DRE with 2 DREs, and 170 voters per DRE with 4 DREs. 150 voters per DRE would be a good starting value.

0.1% may seem very conservative, but there are over 7600 polling places in New York.[22] Thus failures of 1 per 1000 polling places could have 8 pollsites with maximum waits over 30 minutes.

If we assume a 75% maximum turnout, then 150 actual voters per DRE translates to one DRE for every 200 registered voters, i.e. 3 DREs for every lever machine. This is not too different from the requirement of 1 DRE for every 175 registered voters in Ohio which is supposed to be enforced in 2013.[4] Of course New York's full face DREs at $8,000 each will be much more expensive than DREs for Ohio.

This calculation of voters per DRE does not take into account DRE outages or voters with special needs who will take a long time to vote. This will tend to increase the number of DREs needed.

Appendix Conclusion

Queuing theory is an important tool in the understanding of voting system use. Because there are busy and slack periods during the voting day, and because people do not arrive at a uniform rate, the number of people that can vote on a given system is far less than is calculated by simply dividing the total Election Day time by the time for an individual to vote. Any voting frequency figures obtained by the NY State Board of Elections should be analyzed in the framework of queuing theory.

Acknowledgements

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Appendix C

NYVV Submission to the New York State Board of Elections
January 2007

William A. Edelstein, Ph.D., New Yorkers for Verified Voting
"Estimating the Number of Voting Machines for
New York State's Polling Places"

http://www.nyvv.org/newdoc/VotingMachineNumbersForNYS.pdf

New Yorkers for Verified Voting

Estimating the Number of Voting Machines for New York State's Polling Places

William A. Edelstein, Ph.D.
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January 30, 2006

As New York implements the Help America Vote Act, it is imperative that there be enough voting machines to cope with fluctuations in voter arrival times, machine breakdowns, ballot complexity, and variations among polling places. The "Voter System User Rate Assessment Study" carried out by AIR (American Institute of Research)[1] unfortunately does not address the critical question: How many voters can use each voting machine in one day? This is because the AIR study leaves out many important factors, most notably, the effect of uneven voter arrival and concentration of voters during peak periods of the Election Day. Also, its assessment of the needs of voters with disabilities is inadequate.

Taking into account the AIR figures for the time needed to vote on a DRE or mark a paper ballot in a PBOS system (paper ballot/optical scan) along with other data, and applying our own analysis[2] of the effects of variable voter arrival times and Election Day busy periods, we have produced guidelines for voting machine numbers.

Our Recommendations

DREs	1 DRE per 200 non-disabled registered voters. 1 additional DRE per 60 registered voters who want to use accessibility features.
PBOS	1 marking booth per 200 non-disabled registered voters. 1 scanner per 4,000 registered voters 1 ballot marking device (BMD) per polling place. In a large precinct, 1 BMD per 60 registered voters who want to use accessibility features.

Our DRE figures are similar to the requirement in Ohio for one DRE per 175 registered voters[3] that is scheduled to be in place by 2013.

They are also consistent with the experience of a voting precinct in Nashville, TN with two DREs. This arrangement worked well in the 2006 primary with 214 total voters (107 per DRE) but had very long lines in the 2006 general election with 527 voters (263 per DRE).[4]

The figures for PBOS are consonant with a New Hampshire requirement for a maximum 125 actual voters per marking booth[5] and 91 actual voters per marking booth in Lee, MA.[6] Both New Hampshire and Massachusetts have 13-hour Election Days compared to New York's 15-hour Election Day.

Londonderry, NH accommodated 6,000 actual voters in 2004 with a single scanner and no lines.[4] We suggest that—with undervote notification turned on in New York—one scanner per 3,000 actual voters, or one scanner per 4,000 registered voters, will be sufficient here.

Since DREs cost more than $8,000 each and marking booths less than $200, the acquisition cost for DRE systems will be much greater than that for PBOS, where a single $6,000 scanner can serve many marking booths. In addition, the costs for software purchases, annual license fees, and maintenance are substantial and will be greater with DREs, since many more DREs will be required.

Underestimating the number of DREs would be far more problematic than miscalculating the required number of marking booths. On Election Day, it would not be possible to quickly get more DREs. However, it would be feasible to use simple cardboard screens on tables for voter privacy instead of marking booths. Londonderry, NH has a supply of these to accommodate an unexpected surge of voters with their PBOS system.[5]

We finally note that AIR did not ascertain how many voters might want to use accessibility features. This number is critical for determining how many voting machines will be purchased for that purpose, and remains to be estimated or researched.

Our Calculations

We begin with a figure of 3 minutes for a non-disabled voter to vote on a DRE or mark a paper ballot in a PBOS system. We use a possible maximum voter turnout[2] of 75%. "MDR" as defined by AIR[1] is the "maximum daily rate" of people that could use a machine if (in this example) everybody came at exact 3 minute intervals and took exactly 3 minutes to vote.

Non-disabled voters

MDR: 900 minutes per day /3 minutes to vote = 300 voters per machine or marking booth

Adjust for peak voting times: 300 voters/2 = 150 actual voters per machine or marking booth

Registered voters: 150 actual voters/75% max turnout = 200 registered non-disabled voters per machine or marking booth

Voters using accessibility features

MDR: 900 minutes per day /10 minutes to vote = 90 voters per DRE or ballot marking machine

Adjust for peak voting times: 90 voters/2 = 45 actual voters per DRE or ballot marking machine

Registered voters: 45 actual voters/75% max turnout = 60 registered voters per DRE or ballot marking machine using accessibility features

Scanners

Londonderry, New Hampshire: 6,000 actual voters per scanner in a 13-hour election day, no lines[5]

New York: Turn on undervote notification: 6,000/2 = 3,000 actual voters per scanner in a 15-hour election day

New York registered voters: 3,000 actual voters/75% = 4,000 registered voters per scanner in a 15-hour election day

Why our conclusions about the number of DREs differ from the AIR study

- The AIR study measures the time spent on each voting machine. It then divides this time into the total Election Day (900 minutes) and determines what it calls the MDR (maximum daily rate). The MDR is, however, a large overestimate of the number of voters that can actually use any voting machine without creating long lines.[2]
- The cycle time for voters is the total time between voters and therefore must include the times before and after voting when the voter approaches or leaves the voting booth, and the next voter recognizes that it is time to go from the line to the booth. This must add at least 1/4 minute (15 seconds) to the times determined by AIR.
- The AIR report does not explain when or how participants were instructed to check the VVPAT. A number of participants in these studies have told us that the VVPAT was not mentioned when they received instructions. The AIR report itself suggests that the Liberty VVPAT, in particular, is so obscure that the Liberty voting time was artificially shortened (ref 1, page 38). If someone really

wants to check their votes on the Liberty machine, therefore, it would be necessary to allow at least an additional 30 seconds to check that machine's VVPAT.

- There is a wide variation of voting times in the AIR study ranging from just under 3 minutes to over 5 minutes. The total voter cycle time (as explained above) would be slightly longer. All figures had large standard deviations. For the purpose of our calculation we assume—somewhat optimistically—that, with experience, the average voting time for non-disabled voters on a DRE or paper ballot could come down to 3 minutes.
- The AIR report does not take peak voting times into account. A good estimate of the number of voters using each machine in an Election Day, based on our study of peak voting and queuing effects,[2] can be determined as follows. Divide the voting cycle time into the total Election Day minutes, and then divide that number by 2. In this way, according to our calculations, the length of queues should be minimized.
- Regarding voters with disabilities, the AIR report is vague. On page 39 they say that these "MDR estimates [for voters using disability aids] may be misleading" because they don't know if their sample is representative. In fact, they don't have any data on any correlation between the nature of the disability and the voting time. Given that some of the times for voting using accessibility features measured by AIR were on the order of 10 minutes, and some of the times measured by the SBOE were over 30 minutes,[7] we estimate 10 minutes per voter using accessibility aids.

Why our conclusions about paper ballots/optical scan differ from the AIR study

- Paper ballot-optical scan (PBOS) systems are generally used with many marking booths and a few scanners. In some of its results AIR combined the time in the marking booth with scanning time; this is irrelevant. The real questions are: how much time to mark the ballot and how much time to scan?
- In the AIR study, the scanner attendant went through an unnecessarily long statement before the ballot was accepted. Also, not all ballots will be undervoted in real elections. Thus this test process inflated the time to scan.

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Appendix D

NYVV Submission to the New York State Board of Elections March 2007

"New York State BOE Proposal for Numbers of Voters per Machine Guarantees Long Lines and Voter Disenfranchisement"

http://www.nyvv.org/doc/Resp070326.pdf

New Yorkers for Verified Voting

New York State BOE Proposal for Numbers of Voters per Machine Guarantees Long Lines and Voter Disenfranchisement

March 26, 2007

Don't risk electoral meltdown

Recently NYVV submitted a proposal to the New York State Board of Elections detailing why New York should allow no more than 200 registered voters per DRE and 4,000 registered voter per optical scanner.[1] This was based on queuing theory simulations of elections with DRE voting times of 3.25 minutes[2] and other evidence which we will discuss below.

On March 16, 2007, the New York State Board of Elections announced a proposal suggesting we could have one DRE per 527, 548 and 752 voters per Sequoia, Avante and Liberty voting machines. *These results are supposedly based on the AIR measurements[3] but, in fact, are in direct contradiction to those results and will lead to serious electoral problems if implemented.*

Therefore we urge the Board to vote against that proposal and, instead, to institute the numbers we recommend in our study. While our results may seem conservative, it is important to remember that elections are events with many unpredictable factors. In order to make sure that no electoral districts—even a small fraction of the total—have long waiting times, it is necessary to have a adequate excess capacity. Our proposal, based on queuing theory and actual usage data from polling places, are the right choice for New York.

Real-world experience with lever machines and DREs

Susanne Scarpa, the town clerk in Lee, MA, says that they used to have 8 lever machines for 3800 registered (active) voters, i.e. 475 registered voters per machine, and "long, long lines."[4]

A voting precinct in Nashville, TN, with two DREs had 214 actual voters in the 2006 primary (107 per DRE) which worked well. When they had 527 actual voters in the 2006 general election (263 per DRE), they "had some voters waiting in long lines to cast ballots 5½ hours after polls closed."[5]

After its disastrous experience in 2004 and problems in 2006, the state of Ohio has prescribed a limit of 175 registered voters per DRE (starting in 2013).[6]

These numbers are consistent with our figure of 200 registered voters per DRE for New York.

Paper ballots/optical scan is the way to put voters first

Ms. Scarpa of Lee, MA mentioned above went from 8 lever machines with "long, long lines" to paper ballots and a single optical scanner. Lee's 35 marking booths with 3200 actual voters in 2004 had no lines.[4]

Londonderry, NH used paper ballots and had 12,000 actual voters processed with two optical scanners in 2004, i.e. 6,000 actual voters per scanner.[7] We believe that such a scanner, even with undervote notification turned on, could process 3,000 actual voters and serve 4,000 registered voters, assuming a 75% turnout.

Londonderry had 100 marking booths and no lines for the marking booths.[7]

The AIR study[3] said (Exhibit 5, page 21) that ballot marking took 3-4 minutes, a time comparable to the time to use DREs. Marking booths for PBOS represent the same potential choke point for voter flow as do DREs. The difference is that it is easy to avoid traffic jams with PBOS by buying many marking booths at less than $200. But it is prohibitively expensive to buy a comparable number of DREs at a cost of $8,000 or more each.

Queuing Theory

Queuing theory is the mathematics governing lines.

The results of a queuing theory election simulation gives a statistical spread of results that will occur in an election.[2] Not every election district will have long lines. But what if 10% or even 1% have long lines? New York has over

7,600 polling places.[8] A 10% failure would have 760 polling places with long lines and a 1% failure would affect 76 polling places. Long lines and the resulting wait times will cause voters to leave without voting. Even for 76 polling places, this is unacceptable.

We note that the high degree of statistical confidence required means that one cannot predict what will happen by simply asking a few precincts how their lever elections have gone. First, one must know the exact conditions of these elections—how many lever machines, how many voters, and their arrival times. If only 10% or 1% had long lines under certain conditions, an assurance that everything was fine will not tell you what will happen in a large statistical sample, i.e. the whole state of New York. The best predictor of that is queuing theory.

We do know, however, that Lee, MA had "long, long lines" with 475 registered voters per machine.[4] *When trying to predict rare events, existence of those rare events is more telling than many reports that nothing untoward happened.*

Problems with the proposal before the BOE

We consider a specific example to show why the proposal before the BOE is incorrect and fatally flawed. According to the AIR report[3] (Exhibit 5, pg 21), voters took a "trimmed" average of 3:53 to vote on the Avante DRE. Dividing that into a 900 minute (15 hour) day, AIR obtains a "Maximum Daily Rate" (MDR) of 232 voters (Exhibit 10, page 26).

Note that they call it the Maximum Daily Rate.

In fact, 232 people taking an average of 3:53 each could never actually vote in a 15 hour day without the forming of long lines, given that the voters will arrive randomly, there will be extra voters at peak hours, there will be breakdowns, and there will be voters who may each take more than 30 minutes because they need accessibility aids.[9]

How, then, could an Avante DRE serve 548 registered voters? Even a 50% turnout would have to process 274 voters, well beyond the 232 "Maximum Daily Rate" determined by AIR and far, far more than any truly practical number. In the 2004 election, the New York statewide turnout was 60%, which would be 328 voters. The Lee, MA 2004 election[4] and the Londonderry, NH 2004 election[7] both had a turnout of over 80%.

The New York State Board of Elections must reject the current proposal, which will condemn thousands upon thousands of New York State citizens to long lines and voter disenfranchisement. Please don't take risks with our elections.

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Appendix E

NYVV Submission to the New York State Board of Elections
May 2007

"Survey Data on the Number of Voters per DRE in Other State Jurisdictions"
Marge Acosta, NYVV Long Island Representative

http://www.nyvv.org/newdoc/StateTimingData.pdf

Survey Data on the Number of Voters per DRE in Other State Jurisdictions

By Marge Acosta
NYVV Long Island Representative

The New York State Board of Elections is currently considering the question of the maximum number of registered voters who can be served by each type of voting system. It is essential to correctly determine this number in order to ensure that long lines do not form at the polls at peak voting times. At a meeting on March 27, 2007, New York State Election Commissioners adopted a proposal for public comment suggesting that a single DRE can adequately accommodate 550 registered voters. But data from other states and simulations using queuing theory (the mathematics of waiting lines), have shown that 550 voters per DRE is too large by at least a factor of 2.5!

Jurisdictions in DRE states report problems with long lines, even those using far fewer voters per DRE than the New York State proposal. In order to get some guidance from the practices of other states already using DREs, I contacted election officials in six jurisdictions – Lincoln, Tennessee; Cheyenne, Colorado; Carson City, Nevada; Esmeralda, Nevada; Clark, Nevada; and Palm Beach, Florida – to determine what ratios of registered voters to DREs they use, the length of time spent waiting in lines at the polls, and other relevant data.

The table below gives a simple outline of the key results. The full set of data is presented on the following pages. Of immediate note is that voter to DRE ratios used in other states are significantly smaller than the 550 voters per DRE number proposed by the Board of Elections. Lacking any compelling evidence that New York's DREs will be over twice as fast as any other state, one must conclude that the Board's proposal is far too high and will result in long waiting times and disenfranchised voters.

Since all of the surveyed counties have Early Voting, the actual numbers of voters per DRE are even lower on Election Day than the reported averages. It is significant that 4 of 6 counties use DREs with a VVPAT (which takes additional time for the voter to review), and have on average 175 registered voters per DRE. Of the counties using DREs without VVPAT, Lincoln Tennessee reports on average 328 registered voters per DRE, and Palm Beach Florida reports only 175—375 voters less than the New York State Board of Elections proposal!

These findings strongly suggest that allowing 550 registered voters to vote on a single DRE will bring havoc to New York State's elections, causing long lines and unprecedented voter disenfranchisement.

County and State	Registered Voters	Vendor and DRE	VVPAT	Average Number of Registered Voters per DRE
Lincoln, TN	18,000	ES&S iVotronic	No	328
Cheyenne, CO	1277	Hart eSlate	Yes	213
Carson City, NV	25,000	Sequoia AVC Edge	Yes	184
Clark, NV	803,808	Sequoia Edge II	Yes	179
Esmeralda, NV	667	Sequoia Edge	Yes	74
Palm Beach, FL	779,748	Sequoia Edge	No	175

Survey Data On Number of Voters Per DRE In Other State Jurisdictions

County	Vendor and DRE Model	Registered Voters	Precincts	Poll Sites	No. of DREs	VVPAT	Early Voting Period Length	Number of Early Voters	Absentee Ballot Excuse Type	No. of Absentee Ballots	Hours In Election Day	Average No. of Registered Voters per DRE	App. No. of Voters per DRE on Election Day	Waiting Times in Lines
Lincoln, TN	ES&S iVotronic	18,000	20	N/A	55	No	2 weeks	N/A	Excuse	N/A	10	**328**	N/A	Up to 30 minutes
Cheyenne, CO	Hart eSlate	1277	5	2	6 *(1 for Early Voting)*	Yes	7-10 days	178	No Excuse	308	12	**213**	84	Up to 60 minutes
Carson City, NV	Sequoia AVC Edge	25,000	26	2	136	Yes	12 days	App. 50% of voters	No Excuse	2500 (in 2004)	12	**184**	App. 100	No Waiting
Esmeralda, NV	Sequoia Edge	667	5	3	9	Yes	12 days	N/A	No Excuse	N/A	12	**74**	App. 67	Small lines
Clark, NV	Sequoia Edge II	803,808	1090	336	App. 4500	Yes	14 days	App. 50% of voters	No Excuse	N/A	12	**179**	App. 100	5 minute wait maximum
Palm Beach, FL	Sequoia Edge	779,748	767	N/A	4463	No	15 days	60 to 70,000	No Excuse	60 to 70,000	12	**175**	App.100	Lines during peak hours in 2004

Survey Data On Number of Voters Per DRE
In Other State Jurisdictions

County	Comments	Contact Name	Contact Phone	Contact Date		
Lincoln, TN	Always have at least 2 DREs at each site in case one fails	Sheila Allen, Commissioner	931-433-6220	4/23/07		
Cheyenne, CO	Approximate Usage Times cited are: 5 minutes for general voters 40 minutes for disabled voters	Kay Feyh, Co Clerk	719-767-5685	4/23/07		
Carson City, NV	Takes a minimum of 4 minutes to vote. Usage Time for disabled voter app. 30 minutes.	Alan Glover, County Clerk	775-887-2087	4/23/07		
Esmeralda, NV	7 DREs are used at 3 polling sites. 2 DREs are used for Early Voting.	Lacinda Elgan, County Clerk	775-485-6367	4/26/07		
Clark, NV	Approximate Usage Times cited are: 5 to 20 minutes for general voters 30 to 40 minutes for disabled voters	Steve Pak, Registrar's Asst	702-455-2846	4/24/07		
Palm Beach, FL	Usage Time for disabled voters 15 to 30 Minutes. Not all DREs were accessible, none had Sip&Puff	Tony Enos, Manager	561-656-6227	4/24/07		

Survey Data On Number of Voters Per DRE In Other State Jurisdictions - Lincoln, TN

Lincoln, TN	
County	Lincoln, TN
Vendor and DRE Model	ES&S iVotronic
Registered Voters	18,000
Precincts	20
Poll Sites	N/A
No. of DREs	55
VVPAT	No
Early Voting Period Length	2 weeks
Number of Early Voters	N/A
Absentee Ballot Excuse Type	Excuse
No. of Absentee Ballots	N/A
Hours In Election Day	10
Average No. of Registered Voters per DRE	328
App. No. of Voters per DRE on Election Day	N/A
Waiting Times in Lines	Up to 30 minutes
Comments	Always have at least 2 DREs at each site in case one fails
Contact Phone	Sheila Allen, Commissioner
Contact Name	931-433-6220
Contact Date	4/23/07

Survey Data On Number of Voters Per DRE In Other State Jurisdictions - Cheyenne, CO

Cheyenne, CO	
County	Cheyenne, CO
Vendor and DRE Model	Hart eSlate
Registered Voters	1277
Precincts	5
Poll Sites	2
No. of DREs	6 (1 for Early Voting)
VVPAT	Yes
Early Voting Period Length	7-10 days
Number of Early Voters	178
Absentee Ballot Excuse Type	No Excuse
No. of Absentee Ballots	308
Hours In Election Day	12
Average No. of Registered Voters per DRE	213
App. No. of Voters per DRE on Election D	84
Waiting Times in Lines	Up to 60 minutes
Comments	Approximate Usage Times cited are: 5 minutes for general voters 40 minutes for disabled voters
Contact Phone	Kay Feyh, Co Clerk
Contact Name	719-767-5685
Contact Date	4/23/07

Survey Data On Number of Voters Per DRE In Other State Jurisdictions - Carson City, NV

Carson City, NV	
County	Carson City, NV
Vendor and DRE Model	Sequoia AVC Edge
Registered Voters	25,000
Precincts	26
Poll Sites	2
No. of DREs	136
VVPAT	Yes
Early Voting Period Length	12 days
Number of Early Voters	App. 50% of voters
Absentee Ballot Excuse Type	No Excuse
No. of Absentee Ballots	2500 (in 2004)
Hours In Election Day	12
Average No. of Registered Voters per DRE	184
App. No. of Voters per DRE on Election D	App. 100
Waiting Times in Lines	No Waiting
Comments	Takes a minimum of 4 minutes to vote. Usage Time for disabled voter app. 30 minutes.
Contact Phone	Alan Glover, County Clerk
Contact Name	775-887-2087
Contact Date	4/23/07

Survey Data On Number of Voters Per DRE In Other State Jurisdictions - Esmeralda, NV

Esmeralda, NV	
County	Esmeralda, NV
Vendor and DRE Model	Sequoia Edge
Registered Voters	667
Precincts	5
Poll Sites	3
No. of DREs	9
VVPAT	Yes
Early Voting Period Length	12 days
Number of Early Voters	N/A
Absentee Ballot Excuse Type	No Excuse
No. of Absentee Ballots	N/A
Hours In Election Day	12
Average No. of Registered Voters per DRE	74
App. No. of Voters per DRE on Election D	App. 67
Waiting Times in Lines	Small lines
Comments	7 DREs are used at 3 polling sites. 2 DREs are used for Early Voting.
Contact Phone	Lacinda Elgan, County Clerk
Contact Name	775-485-6367
Contact Date	4/26/07

Survey Data On Number of Voters Per DRE In Other State Jurisdictions - Clark, NV

Clark NV	
County	Clark, NV
Vendor and DRE Model	Sequoia Edge II
Registered Voters	803,808
Precincts	1090
Poll Sites	336
No. of DREs	App. 4500
VVPAT	Yes
Early Voting Period Length	14 days
Number of Early Voters	App. 50% of voters
Absentee Ballot Excuse Type	No Excuse
No. of Absentee Ballots	N/A
Hours In Election Day	12
Average No. of Registered Voters per DRE	179
App. No. of Voters per DRE on Election D	App. 100
Waiting Times in Lines	5 minute wait maximum
Comments	Approximate Usage Times cited are: 5 to 20 minutes for general voters 30 to 40 minutes for disabled voters
Contact Phone	Steve Pak, Registrar's Asst
Contact Name	702-455-2846
Contact Date	4/24/07

Survey Data On Number of Voters Per DRE In Other State Jurisdictions - Palm Beach, FL

Palm Beach FL	
County	Palm Beach, FL
Vendor and DRE Model	Sequoia Edge
Registered Voters	779748
Precincts	767
Poll Sites	N/A
No. of DREs	4463
VVPAT	No
Early Voting Period Length	15 days
Number of Early Voters	60 to 70,000
Absentee Ballot Excuse Type	No Excuse
No. of Absentee Ballots	60 to 70,000
Hours In Election Day	12
Average No. of Registered Voters per DRE	175
App. No. of Voters per DRE on Election D	App.100
Waiting Times in Lines	Lines during peak hours in 2004
Comments	Usage Time for disabled voters 15 to 30 Minutes. Not all DREs were accessible, none had Sip&Puff
Contact Phone	Tony Enos, Manager
Contact Name	561-656-6227
Contact Date	4/24/07

Appendix F

Columbia County Board of Elections Study
May 2007

"Study of Voter Flow at the 2006 General Election,
Columbia County, NY"
Ken Dow, Commissioner of Elections, Columbia County

http://www.nyvv.org/newdoc/county/StudyOfVoterFlowAtThe2006GeneralElection04-27.pdf

http://www.nyvv.org/newdoc/county/VoterFlowStudy2006GE-Final.xls

Study of Voter Flow at the 2006 General Election

Columbia County, NY

Ken Dow, Commissioner of Elections, Columbia County

April 27, 2007

When do voters vote?
How many new voting systems will be required to accommodate them?

As elections officials, we know that polling places are busier during some parts of Election Day than during others. It's also obvious that in order to avoid long lines and wait times for voters, it is necessary to have sufficient capacity to handle the number of voters that arrive at the polling place during the busiest times. Faced with the looming HAVA requirement to purchase new voting systems, we sought to determine the number of voting systems that would be necessary to avoid unacceptably long lines for voters. To make such a determination, we needed to know how many voters came to the polling places at different times during the day.

In order to determine how much traffic should be expected during peak times, it is plainly insufficient merely to divide the total number of voters by the hours in the voting day. We knew simple averaging wouldn't tell us what we needed to know. We decided to get some real numbers.

In order to measure actual voter flow, we asked our inspectors to count and record the number of voters who arrived at each polling place during each 2-hour interval throughout the day at the 2006 General Election. We got data from 56 of our 58 Election Districts. The data and further tools for analysis are in the attached Excel spreadsheet.

The most important information we learned is that during the 15-hour General Election, **between 20 and 25 percent of all voters typically went to the polling place during the peak 2-hour period**. A second important finding was that the results from the different polling places were very consistent with each other. In the great majority of polling places, the peak period was between 4:00 and 6:00 PM. In several polling places the busiest time was between 8:00 and 10:00 AM, and a few polling places peaked at other times. We hope the attached data and tools will help New York boards of elections make cost-efficient judgments about what capacity will be necessary to properly serve the voting public.

In exactly half of the Election Districts, at least 20 percent of voters went to the polling place during the peak 2-hour period. In 25 of the 56 districts, between 20 and 25 percent of voters went to the polling place during the peak 2-hour period, and in 3 districts, more than 25 percent of the voters voted during the peak time. Based on simple averaging—spreading the total number of voters evenly throughout the 15-hour day—13.33% of voters would vote during any 2-hour period. The actual data show that the busiest time is typically between 1 ½ and 2 times as high as the average.

How misleading is averaging?

An example illustrates the consequences of projecting capacity needs based on average number of voters per hour: If we spread 450 voters over a 15-hour day from 6:00 AM to 9:00 PM, we would have an average of 30 voters per hour. But if we only had capacity to handle 30 voters per hour (60 voters over two hours), we would have long lines at certain times of the day.

Given 450 voters and allowing that 20 to 25 percent of voters arrive during the peak, we need to accommodate between 90 and 112 voters in two hours, or we will have lines. If we can accommodate only the average number of 60 based on the entire day's traffic, we will have very long lines.

Imagine in the example above that each voter takes an average of 2 minutes to vote. Each voting machine or system would therefore have a capacity of 30 voters per hour. If you have one machine or system, you can handle 60 voters in two hours. Based on the average flow of voters during the day, one system would be just enough capacity to handle 450 voters. But because some periods are much busier than average, you would actually have long waiting lines at the busiest part of the day. In this example, if 22% of the voters came during the peak 2-hour period, 99 voters would arrive within two hours. Since your capacity is only 60, by the end of the period there will be at least 39 voters waiting in line. Since they each take 2 minutes to vote, the person at the end of the line would have to wait 78 minutes (1 hour, 18 minutes) before they got to vote. That is clearly unacceptable.

It is no surprise to show that if we expect 450 voters, our capacity has to be somewhat greater than that, because we all know the flow is uneven. But what if you expect only 350 voters? Will your theoretical capacity of 450 voters be able to handle 350 actual voters without problems? No. During the peak 2-hour period, you should expect between 70 and 88 voters, and you can only handle 60. The voter at the end of the line will have to wait between 20 and 56 minutes. That's still not good enough.

Basing capacity needs on estimates that essentially spread voters out evenly throughout the day may lead to badly underestimating system needs. Capacity estimates must reflect the concentration of voter activity at peak periods. The data and analysis contained here is a step toward doing that.

Using the attached Excel spreadsheet

The data we collected, along with some analytical tools, are in the attached spreadsheet. The spreadsheet has two sheets, or tabs: "GE Nov 2006" and "Projections."

GE Nov 2006 contains the raw data. Each row shows the Election District, the number of voters who voted during the day, the number who voted during each 2-hour period, and the *percentage* of the day's voters who voted during each 2-hour period. The peak period for each Election District is highlighted in yellow. Below the table are three graphs, which give a pictorial indication of the way voters were distributed throughout the day.

Projections contains several interactive tables that allow you to enter estimates and produce projections. These analytical tools turn estimates of voter flow and time per voter into projections of required capacity. All of the fields highlighted in yellow can be changed. To create different scenarios, enter different numbers into the yellow fields. Note that times must be entered as decimals, not minutes & seconds. (For example, 2 minutes and 45 seconds would be entered as "2.75," NOT "2.45.")

Table A is not interactive, but simply shows the number of voters who would arrive during a given 2-hour period, based on the number of total voters during the day and the percentage who vote during the 2-hour period.

Table B-1 and Table B-2 are linked. Based on the average voting time per voter and the number of voting systems used, Table B-1 indicates the length of time a voter arriving at the end of the peak period would have to wait before voting. For example, if the average voting time per voter is entered as 3 minutes and 2 voting systems are used, the table calculates that each system can handle a maximum of 20 voters per hour (1 hour ÷ 3 minutes per voter) and two systems together can handle 40 voters per hour or 80 voters over a 2-hour period. In an Election District with 500 voters (left column) where 22 percent of the voters come during the peak, 110 voters would arrive. This creates an excess of 30 voters more than capacity. Each of those voters takes 3 minutes, which is 90 minutes of backup. Dividing 90 minutes of backup between the two voting systems means that it would take 45 minutes for the voter at the end of the line to get to the voting booth. When average voting time per voter is set to 3 minutes and number of voting systems is set to 2, the 45 minute wait is indicated at the intersection of 500 and 22.

Table B-2 allows the user to enter the longest period of time that a voter should be permitted to wait in line, and indicates the number of voting systems required to ensure that. Note that the green field for voting time for voter cannot be changed in Table B-2; it is linked to Table B-1 and must be changed in Table B-1.

Table C-1 and Table C-2 do the same calculations as Table B-1 and Table B-2, but for optical scanning systems. The tables are based on data showing that a single optical scanner itself can handle the peak time at any single Election District, and the important variable is the number of privacy booths that are necessary.

Average Voting Time Per Voter

While knowing the number of voters arriving at peak times is crucial to any useful projection of capacity needs, the other vital piece of information required is the average amount of time each voter takes to vote. Unfortunately, in my opinion, we do not have very reliable data on this.

The data produced by the testing so far seems highly questionable. I would hope that we will be able to obtain or produce much more reliable estimates of the amount of time required for each voter than is currently available. In the meantime, we are left to use the data from last year's studies and our own judgment.

Other Considerations

Determining the necessary voting system capacity requires making numerous judgments. Of course we need an accurate estimate of the voting time required for each voter, along with a projection of the number of voters that must be accommodated during peak periods. But we also need to make decisions about tolerable wait times and other issues. Because there is variation among polling places, we need to think about how tolerable it is to have voters waiting, and in how many Election Districts. This is more than I intend to address in this brief memo, but it is a crucial part of the analysis. In the meantime, I hope this information is provocative and helpful.

Ken Dow
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Columbia County