Queuing and Elections: Long Lines, DREs and Paper Ballots

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Abstract

Computerized touchscreen "Direct Recording Electronic" (DRE) voting systems have been used by over 1/3 of American voters in recent elections. In many places, insufficient DRE numbers, in combination with lengthy ballots and high voter traffic, have caused long lines and disenfranchised voters who left without voting. We have applied computer queuing simulation to the voting process and conclude that far more DREs, at great expense, would be needed to keep waiting times low. Alternatively, paper ballot-optical scan systems can be easily and economically scaled to prevent long lines and meet unexpected contingencies. We have developed a heuristic "Queue Stop Rule" that can be applied to prevent long lines at voting stations. We have also carried out queuing simulations of other parts of the voting process, for example, voter check-in and ballot scanning. Our results can be used to help plan cost-effective election systems that will produce expeditious elections.

1. Introduction

The controversial Presidential election in 2000 convinced Congress that US voting technology should be upgraded, and the result was the Help America Vote Act (HAVA) passed in 2002 [1]. This legislation established various rules for voting systems, included provisions to make voting accessible to people with a wide range of disabilities, and funded states to buy new voting equipment.

Most states and voting precincts now have either computer touchscreen "Direct Recording Electronic" (DRE) systems (33% of voters in 2008) or paper ballot-optical scan (PBOS) equipment (56% of voters) [2].

DREs generally use a touchscreen on which voters enter their choices electronically (e.g. [3]). Votes are recorded digitally on a memory card, and totals are read out at the end of the voting day.

With PBOS systems, voters use a pen or pencil to fill in circular or elliptical "bubbles" or complete a line on a paper ballot (e.g. [4]). Completed ballots are fed through a scanner that tallies the votes. The voter-marked ballots are subsequently available for manual or machine recounts or audits.

One concern about DREs, in contrast to PBOS, is that it is not possible to recount or audit paperless DREs and votes have been lost or questioned because of DRE malfunctions [5-8].

This paper addresses another serious problem associated with DREs, namely, the formation of long lines of voters that has occurred repeatedly in many venues across the United States (California, Florida, Maryland, , Ohio, Pennsylvania, Tennessee, Utah and elsewhere [6, 8-14]), sometimes requiring voters to wait several hours to cast their ballots. Inevitably, some voters caught in such situations—for example, the elderly, people with disabilities or illness, people needing to get back to work, parents needing to care for children—leave without voting and are thereby disenfranchised [8, 9]. A common reason that these delays occur is that there are not enough DREs at each precinct to allow voting in a timely and efficient manner. In this case, the voter flow bottleneck for marking ballots is determined by the number of DREs.

In contrast, PBOS systems can be expanded to deal with an unexpectedly large number of voters, or to allow extra time to mark a complex or long ballot, and thereby avoid the formation of long lines. For a PBOS system, the number of ballot marking stations is a potential voter flow bottleneck corresponding to the number of DREs in a DRE system. PBOS marking stations may be as simple and inexpensive as a cardboard screen taped to a table or well-separated desks in a large room. Additional privacy screens can be immediately installed if a need for them becomes apparent. In other words, PBOS systems have a cost and flexibility advantage relative to DRE systems.

Voting congestion is analogous to highway traffic jams. When car numbers are low, traffic flows freely. As vehicle numbers increase, traffic slows gradually until a density is reached at which a few cars become stationary, traffic locks up, and long lines form that can take hours to clear.

Queuing phenomena are highly nonlinear and it is important to understand the tradeoffs. We have quantified: the conditions that produce long lines; the time course of line formation and line contraction; how to configure voting systems to prevent long lines; and the relative merits of DRE and PBOS systems in this context. We hope our analysis can help create efficient election systems that will eliminate long lines and consequent voter disenfranchisement.

Computer simulation code and data for this work are available at http://tinyurl.com/votingQueues.

2. Computer queuing simulations

We have used computer queuing simulation of elections to study voter flow as a function of voter numbers and time to vote [10, 11]. Following these simulations, we have derived a heuristic "Queue Stop Rule" that that can avoid the formation of significant lines.

We have carried out our simulations using Maryland state election parameters. We understand that results may look somewhat different in other venues.

Maryland presently uses Diebold Accuvote TS touchscreen DRE voting machines. In November, 2008, Maryland had 1,824 voting precincts each containing from 17 to 7,505 registered voters with an average of 2,048 [12]. Maryland state regulations (COMAR) require "one DRE for each 200 registered voters, plus an additional voting unit for every fractional part of that number." [13]. The number of DREs per precinct ranged from 2 to 38 with an average of 10.8±4.8 DREs (SD). More than 19,600 of these DREs were needed in 2008 according to the COMAR rule [12, 13].

For illustrative purposes, we consider an election in an average precinct (2,000 total registered voters, 10 DREs) in which individual voting takes an average of 5 minutes and there is a 75% turnout, i.e. 150 voters per DRE. Maryland has a 13-hour Election Day starting at 7 a.m., ending at 8 p.m. We assume three heavy traffic periods—7-9 am, 12-2 pm, and 5 to 8 pm—and suppose that 10% of voters come in each hour during these intervals, while 5% per hour arrive during the rest of the day. We derive wait time statistics by simulating 10,000 elections, assuming a Poisson voter arrival process for the average rates described above. These voter traffic variations are consistent with observations in Columbia County, NY [14, 15].

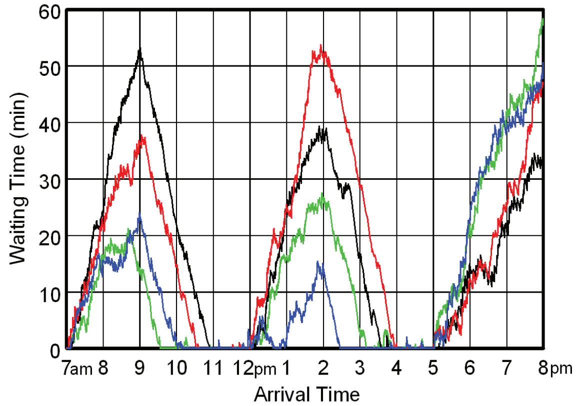

Figure 1. Four election sessions with maximum waiting times over 50 minutes. These occur during morning, lunch or evening heavy voter flow periods. Note that the buildup and decay of long waits--in other words, long queues--is slow, so a long maximum wait is an indication that many voters will have long delays.

Figure 1 shows queuing simulation results for four Election Days with maximum waiting times or late closing times over 50 minutes. The long delays in this simulation occur during heavy voter traffic periods: morning, lunch and evening.

One might ask whether the maximum wait times or closing delays could occur for only a few voters, but this is not the case. It is evident that buildup and decay of waiting times—the development and contraction of long lines—is slow. So a high maximum wait implies a drawn-out election experience for many voters. For example, the four plots in Fig. 1 have 10%-20% (150-300) of all voters waiting over 30 minutes.

2.1 Queuing time distributions vs. precinct size and DRE numbers

Continuing with our assumption of 5 minutes to vote and 150 actual voters per DRE, Figure 2A shows

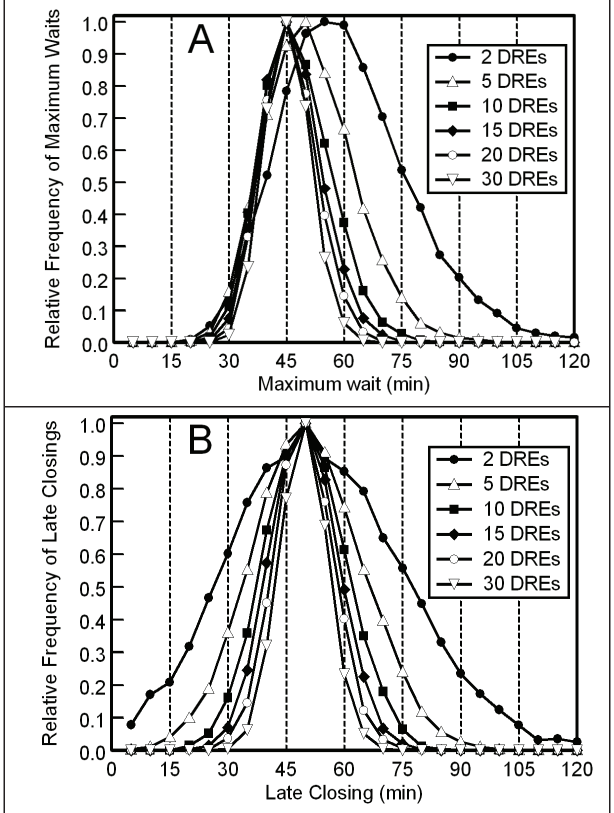

Figure 2. Distributions of (A) maximum wait and (B) late closing times for a precinct with 150 actual voters per DRE in a 13 hour Election Day. Each voter takes 5 minutes to vote. 10% of the voters arrive each hour between 7-9 am, 11 am-1 pm, and 5 pm - 8 pm. 5% of the voters arrive during each of the other six hours. 10,000 elections were simulated and the results normalized so that the maximum has value = 1. More machines smooth fluctuations and produce narrower distributions, even though there are still 150 voters per machine.

distributions of maximum waiting times (the longest time a voter waits in each of 10,000 elections) for precincts with different numbers of DREs, and Figure 2B shows distributions of late closings. The curve for "2 DREs" corresponds to a precinct with $2 \times 150 = 300$ voters, "10 DREs" is a precinct with $10 \times 150 = 1,500$ voters, and so on. The widths of these distributions are a result of voter number fluctuations, and it is apparent that precincts with more DREs smooth out the variations.

It is worth noting that variations of the voting times for each voter—for example, if the voting times were distributed around an average of 5 minutes with a Gaussian or some other distribution—will not have a significant effect, as queue formation is a collective phenomenon. The "piling up" of voters to form a queue depends on the total time to vote for many voters forming the queue. Thus fluctuations in individual voting times or arrival times will not substantially change the onset of queue formation or the length of queues.

We can find the fraction of precincts with specific waiting times or late closing delays by determining the fractional area under each curve in Fig. 2 starting with the time of interest. For example, 82.5% of precincts with 2 DREs will have maximum waits of more than 45 minutes compared to 59.1% of 10-DRE precincts. 63.2% of 2-DRE precincts will have greater than 45-minute overtimes compared to 68.6% of 10 DRE precincts. Tables 1A and 1B show these values for a series of maximum waits and closing delays.

2.2 Queue formation: varying voting times and numbers of voters

To test the sensitivity of queue formation to changing parameters, we carried out 100,000-voter election simulations for a 10-DRE precinct, varying the time to vote and number of voters per DRE.

Fig. 3(A) shows the fraction of precincts with various waiting times as a function of the time needed to vote assuming (as above) precincts with 150 actual voters per DRE. Figure 3(B) displays the same fraction vs. number of voters per DRE in precincts assuming a voting time of 5 minutes.

Both these plots illustrate the extreme sensitivity of the generation of long lines/waits to polling place conditions. From Fig. 3(A), a 4.6 minute voting time would result in only 0.1% of precincts with a maximum wait of over one hour. But a 5 minute voting time would cause 10% of precincts to have one-hour waits. 138 voters per DRE in Fig. 3(B) cause 0.1% of precincts to have greater than one hour maximum waits, but 10% of precincts would have those kinds of waits with 150 voters per DRE.

So a 9% change of time to vote, or a 9% change in

Table 1A. Fraction of precincts that will have the maximum waiting times specified as a function of the number of DREs in the precinct. Statistics were calculated from 10,000 simulated elections assuming 150 voters per DRE, each taking an average of 5 minutes to vote, with a 13 hour Election Day.

	>15 min	>30 min	> 45 min	> 60 min	> 75 min	> 90 min	> 105 min	> 120 min
2 DREs	100.0%	98.6%	82.5%	47.4%	18.3%	5.6%	1.2%	0.3%
5 DREs	100.0%	98.6%	69.2%	21.3%	2.9%	0.2%	0%	0%
10 DREs	100.0%	99.0%	59.1%	9.6%	0.3%	0%	0%	0%
15 DREs	100.0%	99.4%	54.8%	5.1%	0%	0%	0%	0%
20 DREs	100.0%	99.7%	53.6%	2.6%	0%	0%	0%	0%
30 DREs	100.0%	99.9%	51.5%	0.7%	0%	0%	0%	0%

Table 1B. Fraction of precincts that will have long closing delays specified as a function of the number of DREs in the precinct. Statistics were calculated from 10,000 simulated elections on Election Day.

	>15 min	>30 min	> 45 min	> 60 min	> 75 min	> 90 min	> 105 min	> 120 min
2 DREs	96.6%	85.8%	63.2%	37.1%	16.7%	5.7%	1.4%	0.40%
5 DREs	99.6%	92.9%	65.3%	25.7%	4.7%	0.4%	0.02%	0%
10 DREs	100.0%	97.6%	68.6%	17.6%	0.9%	0.02%	0%	0%
15 DREs	100.0%	99.2%	71.6%	12.5%	0.3%	0%	0%	0%
20 DREs	100.0%	99.6%	75.0%	9.0%	0.03%	0%	0%	0%
30 DREs	100.0%	100.0%	79.1%	4.9%	0%	0%	0%	0%

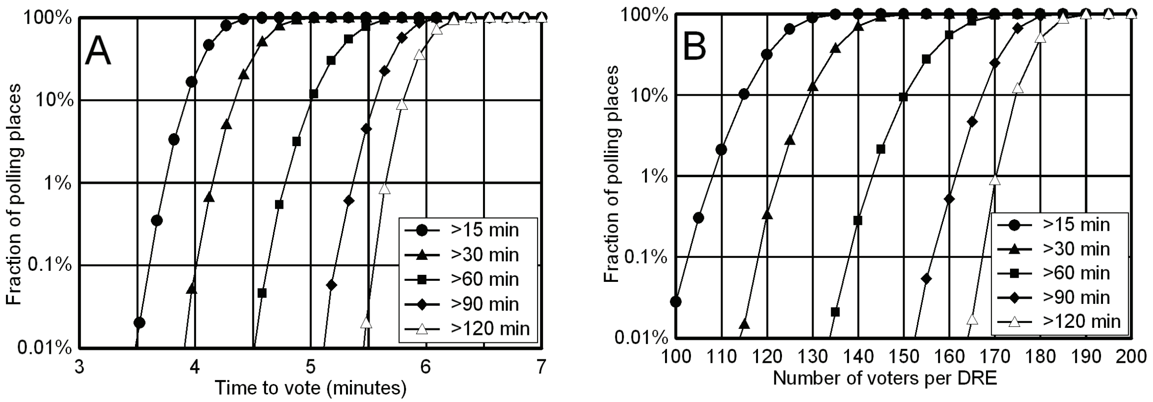

Figure 3. (A) Fraction of polling places with maximum waiting times vs. time to vote, given 150 voters per DRE and (B) number of voters per DRE given a 5 minute voting time and different numbers of voters per DRE. 100,000 elections were simulated for each data point. The results show that small changes in time to vote (A) or voters per DRE (B) produce big changes in the fraction of polling places with long waits.

number of voters per DRE, causes a 100X increase in the number of precincts with greater than 60 minute maximum waits.

3. Queue Stop Rule

As mentioned above, the number of marking booths for PBOS plays the same role as the number of DREs for a DRE system. We will now use the term "voting stations" to indicate either DREs or paper ballot marking booths.

Given the sensitivity of waiting times to small changes in voter numbers and voting times, can we specify a number of voting stations that will virtually eliminate long lines? In general we know that such a rule must provide a substantial reserve of voting stations in order to cope with highly variable election conditions.

We therefore define a heuristic "Queue Stop Rule" that can be applied to a range of voting situations.

We begin with a generalized view of queuing results as a contour plot of waiting times vs. voting time and voter numbers (Fig. 4). The closeness of the contours again indicates the sensitivity of waiting times to voter numbers and average voting times.

We should choose operating conditions safely below the lowest trace on the plot that causes queues, i.e. 0.1% probability of having queues > 15 min. To keep things simple, we suggest a "Queue Stop Rule" which is calculated using the formula

$$\boxed{\textbf{Queue Stop Rule}: NV_{VS} \le \frac{1}{2}\left(\frac{T_{Day}}{T_{Vote}}\right)} \qquad (1)$$

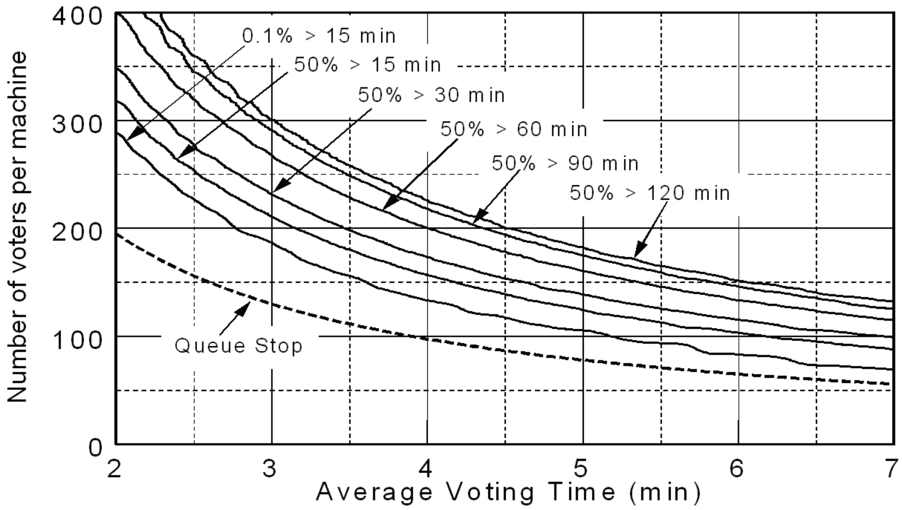

Figure 4. Maximum waits as a function of average voting time and number of voters per voting station (DRE or ballot marking station) for a precinct with 10 voting stations. The "Queue Stop Rule" that would make long lines rare is calculated from the formula $NV_{VS} \times T_{Vote} \le T_{Day}/2$. Its curve lies well below the contours for even a 15-minute wait. The extreme sensitivity of maximum waiting times is again exhibited by the closeness of these contours.

where NV_{VS} is the number of voters per voting station in a day, T_{Day} is the total minutes in the Election Day and T_{Vote} is the number of minutes it takes each voter to mark a ballot.

The contour for the Queue Stop Rule, Eq. 1 above, has been plotted on Fig. 4 and is well below the other curves.

The Queue Stop contour should therefore virtually eliminate the chance of long lines if the combination of average voting time and number of voters per voting station are on or below that line.

However, it is still possible that an unexpected fluctuation—a long ballot or extra voters—might push the queuing product $NV_{VS} \times T_{Vote}$ higher in the plot where long waits become probable.

As a sanity check, we consider what would happen if one were to specify that the number of voters per voting station should equal the number of minutes in a day divided by voting time needed by each voter, i.e. $NV_{VS} = T_{Day} / T_{Vote}$, which is twice the number specified by Eq. 1.

A 13-hour voting day (780 min) and 4 min to vote would give 780/4 = 195 voters per voting station. This would work only if voters came along at exact 4 minute intervals. Even if the average voter flow were constant throughout the day, fluctuations of voter arrivals would result in small pileups. Surges would result in major pileups, as we have demonstrated. Our Queue Stop Rule (Eq. 1), specifying half the number of voting stations obtained by assuming clockwork voter attendance, should have enough capacity to make long line formation extremely rare.

4. Queuing simulation applied to check-in and scanners

We can also apply queuing simulation to ballot scanning and to the check-in process to investigate the queue-causing tendencies of these systems.

In the voting documentary “Bought and Sold,” ballots pass through two different ballot scanners in less than 1 s each [16]. However, the total cycle time between corresponding positions for consecutive voters must include the time to walk to and leave the scanner.

The cycle time for a very simple scanner that just accepts and processes the paper could be 5 s or less. If the voter has to look at a scanner display which indicates over- or undervotes, the time may increase, say to 10 s or more. (An “undervote” means that the voter has not made a choice in one of the ballot contests; an “overvote” occurs when a voter has improperly chosen too many candidates.) Scanning a ballot plus inspecting a ballot image could take 30 s to 60 s or longer.

We have simulated queues caused by times corresponding to ballot scanning and check-in processes and calculated the probability of maximum waiting times for various numbers of voters taking 5 s, 10 s, 30 s or 60 s for these voting stages. Table 2 shows the number of actual voters that would cause waits of greater than 15 minutes in 0.1% of precincts (Col. 2), the number of actual voters specified by the Queue Stop Rule (Col. 3) and the maximum number of registered voters (assuming a 75% turnout) for the cycle time listed.

A single scanner with a voter cycle time of 5 s could therefore support 4860 actual voters or 6480 registered voters. If two sheets of paper are needed, then the cycle time might move toward 10 s, in which case a single scanner would support about 2340 actual voters and 3120 registered voters. (Voting scanners generally scan both sides of a single sheet simultaneously.)

Some modern scanners have increased “features” such as ballot imaging, and most are capable of undervote or overvote notification. If this causes voters to slow down significantly, then scanners could become the bottleneck. According to the AIR study of voting systems in NY [17], the scanning process took about 30 s. Unfortunately, they did not give any details of how this measurement was carried out. 30 s would suggest one scanner for approximately every 1,000 registered voters (see Table 2). That number of scanners is well above what is commonly used or projected, for example, for Maryland, i.e. one scanner each for most precincts. Thus it is important to make sure that the scanning process is fast.

In Maryland, the largest single precinct has 7505 registered voters [12]. A 75% turnout for this precinct would be 5629 voters, somewhat over the limits for a single, simple scanner taking 5 s per voter. A 75%

Table 2. Number of voters per electronic pollbook or paper ballot scanner vs. voter cycle time. Col. 2 shows the number that would result in ≥ 15 min lines in 0.1% of precincts. Col 3 shows Queue Stop Rule calculation of maximum actual voters, and Col. 4 shows Queue Stop Rule calculation of maximum registered voters.

Voter cycle time (s)	Actual voters per device causing 0.1% of precincts to have waits ≥15 min	Queue Stop max # of actual voters per device	Queue Stop max # of registered voters per device (assume 75% turnout)
5	7280	4860	6480
10	3504	2340	3120
30	1017	780	1040
60	420	390	520

turnout giving 2,340 voters (10 s per voter) corresponds to 3120 registered voters. In Maryland, about 258 out of 1824 polling places have more than 3120 voters. Thus a large majority of Maryland polling places could function well with a single scanner and voter cycle time 5-10 s.

We can also consider possible queues at the check-in database terminals known as "E-Pollbooks" in Maryland. WAE has served as an election worker in Maryland for several elections and has measured the average check-in time to be approximately 50 s. This was done by observing the time for several groups of 10 voters to get through the check-in process and dividing by 10. Applying the last row of Table 2 and a cycle time of 60 s, we conclude that there should be at least one check-in terminal for every 390 actual voters or 520 registered voters based on 75% turnout.

It is important to note that long lines caused by insufficient DREs/marking booths can look deceptively as if the lines are caused by the check-in process. During the 2008 general election in Maryland, lines containing hundreds of voters formed behind the check-in station at the precinct (in a Baltimore school) where WAE was an election worker. However, during the periods with long lines, there were never empty DREs.

The reason for this situation is that there are a limited number of "smart cards" available. (A smart card is used by each voter to activate a DRE.). Once all smart cards are handed out, voters lining up to check in have to wait until some smart cards have been used and returned. Also, there is limited space between the check-in tables and the DREs, whereas the long line waiting for check-in extended well out the door towards the street. Thus even without the smart cards, election workers would not check in voters until the line between check-in and voting systems cleared a bit.

Having the check-in as the true bottleneck would require the appearance of empty DREs or empty marking booths in a PBOS system.

4.1 The Queue Stop Rule and Maryland

Maryland has a 13-hour voting day (780 minutes). Suppose voting takes on average 4 minutes per voter. This gives $NV_{VS} \le (1/2)\times(780/4) = 97.5$. So there should be at least 1 voting station for every 98 actual voters.

Assuming a potential 75% turnout, NV_{Reg}, the number of registered voters per voting station, is related to the number of actual voters per voting station by

$$NV_{Reg} = NV_{VS}/75\% \qquad (2)$$

Continuing our example, we should therefore have at least one voting station for each $NV_{Reg} = 97.5/75\% = 130$ registered voters. This is about 50% more voting stations than the number of DREs prescribed by Maryland law, which specifies one DRE per 200 registered voters [13].

We can rearrange the Queue Stop Rule (Eq. 1) to find a recommended average voting time for a given set of election parameters.

$$T_{Vote} \le \frac{1}{2}\left(\frac{T_{Day}}{NV_{VS}}\right) \qquad (3)$$

200 registered voters per DRE specified by Maryland law [13] would give $NV_{VS} = 150$ actual voters for a 75% turnout.

Eq. 3 says $T_{Vote} \le (780\,\text{min}/150)\times(1/2) = 2.6\,\text{min}$. If T_{Vote} exceeds this value, then long lines might start to appear.

The paper ballot marking station in a PBOS system represents the same potential choke point for voters as does a DRE. The high cost of DREs, however—about $2,700 each in Maryland [18]—compared to inexpensive ballot marking privacy booths ($200 [19]) or cardboard screens (a few dollars) means that it is far more economical to provide a large reserve capacity for ballot marking than to do the same for DREs.

If long lines suddenly develop, extra paper ballot marking capacity can be quickly implemented—for example, by taping extra cardboard screens to tables, or by sending voters to scattered desks. It is logistically impractical to bring in additional DREs, even assuming that the local election jurisdiction has extras.

5. Considerations for designing efficient election systems

In principle, it would be possible to take a ballot, test it on a representative group of voters and figure out how many voting stations to have in every voting venue in an election. However, since primary elections are sometimes held in September with the general election following in November, there really is not enough time to carry out this program, especially since different regions in the same state may have different numbers of races and/or ballot propositions.

What would be helpful is a general strategy, which we outline here, and a suggested starting point for the number of voting stations.

We estimate an average voting time using available data, which, unfortunately, is sparse. A study for New York State by the American Institutes of Research concluded that ballot marking took 3-4 minutes [17]. This did not include time to approach the voting machine/ballot marking station, so the cycle time is a bit longer. A study of the general election in Columbia County, NY in 2006 estimated voting time to be about 3 minutes [14, 15]. A recent study of the 2008

California primary concluded that voters took 3 minutes in the voting booth in Napa County, 3 minutes 25 seconds in Alameda County and 4 minutes 30 s in San Mateo County [20].

We therefore take 4 minutes as a reasonable estimate for the voting cycle time.

We can also gain some insight by looking at previous long lines and what it took to eliminate them.

Lee, Massachusetts, with 3800 active voters changed from eight mechanical lever voting machines to PBOS with 35 marking booths and one scanner. In the 2004 general election, 3200 people voted in Lee. The town clerk Suzanne Scarpa said that the lever machines in the past had caused "long, long lines," but that there were no lines for the marking booths or the scanner [16]. So Lee had 3200/35 booths = 91 voters/marking booth.

In the 2004 General Election, Londonderry, NH used 100 marking booths for 12,000 actual voters, i.e. 120 voters/marking booth, and had no lines [21].

Looking at the Queue Stop contour in Fig. 4, 4 minutes suggests using one voting station (DRE or ballot marking station) per 100 actual voters, or one voting station per 133 registered voters for a 75% turnout. These figures are roughly consistent with the numbers in Lee, MA and Londonderry, NH where long lines did not occur.

It is also true that Maryland did not have lines in several elections (for example, the 2008 primary) where turnout was only 32% [22].

It would be prudent, therefore, to get 1 marking station per 130 registered voters. However, not all the marking stations may have to be deployed in every election, especially when turnout is expected to be low. By similarly applying the Queue Stop Rule, there should be one check-in position per 400 registered voters (assuming 60 s to check in) and one scanner per 3,000 registered voters (assuming 10 s per voter).

We note that the time to check in voters, and the time to scan ballots, should not vary substantially from election to election. Therefore these times could be measured for particular equipment and an accurate estimate of the needed capacity obtained. The voting process (DREs or paper ballots) is much more variable because of the changing number of contests and propositions from election to election.

6. Discussion and conclusions

Our example state, Maryland, has over 1800 polling places. If 180 polling places (10%) or 18 polling places (1%) or even 2 (0.1%) were seriously congested with long delays for voters, there could be significant effects on local, regional or national elections and consequent political disputes. As noted by Clive Thompson, "voting requires a level of precision we demand from virtually no other technology." [5]

The 2004 and 2006 Maryland elections had a large number of voting precincts with very long lines. The 2006 ballot in Prince George's County had 37 items including election contests and ballot questions (aka "propositions" or "referendums" elsewhere) [23].

The 2008 Presidential election was hotly contested and Maryland had a statewide turnout of over 77% [24]. Some ballots were lengthy. In addition to the Presidential, Congressional and other electoral contests, there were two statewide ballot questions and many local ballot questions: 7 for Prince George's County, 11 for Baltimore County and 16 for Baltimore City [25].

Thus conditions were ripe in 2008 for long lines in Maryland and other places that use DREs, with consequent disruption of the voting process. The Ohio Secretary of State expressly directed Ohio election workers to use paper ballots to relieve congestion caused by DREs [26], and Indiana and California were similarly prepared. Unfortunately, Maryland refused to adopt this policy, as was the case with a number of other states [27].

In the event, Maryland did in fact have long lines approaching two hours for much of the morning in many venues around the state [28, 29]. The lines decreased at about noon and the waits were short in most places for the rest of the day.

The Maryland formula [13]—1 DRE per 200 registered voters or 150 actual voters, given a 75% turnout—was clearly not enough. Our calculations indicate that a 75% turnout, and a 4-minute or longer voting time average, suggests the use of one voting station per 130 voters, i.e. about 50% more voting stations than are specified by Maryland law, to maximize the chances for a smooth election.

As we have indicated through computer queuing simulation, and as has occurred in real life, the incidence of long lines depends on many uncontrollable factors and is difficult to predict. The only way to mitigate this problem and have efficient voter flow is to have a substantial excess capacity for each stage of the voting process. This can be accomplished, and is only financially and logistically practical, through the use of paper ballot systems.

Finally, further observational data on voting times and voter cycle times are sorely needed. These data can be used in conjunction with queuing simulation to help decide how much equipment is required for each step of the voting process, and thus help specify cost-effective equipment that enables expeditious voting. Studies of line formation during elections would be very instructive in refining our model. Both these studies must be planned well in advance, as observers in voting venues making these kinds of measurements very likely require legal permission.

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