Data Analysis and Simulation: Optimizing Voter Wait Times

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Abstract - **The bipartisan election commission formed after the 2012 election recommended that no American should wait longer than 30 minutes to vote. However, in every presidential election year, stories surface of voters having to wait several hours. Long lines disrupt voters' schedules and hinder economic activity, but can also discourage voters from remaining in line to vote. One way to decrease the average and maximum voter wait times is to better prepare polling locations by staffing optimally and having enough voting booths available. Data was collected from a Williamsburg polling location in Virginia during the off-year November 2015 delegate election. Simulation analysis found that in order to have maximum wait times of less than 30 minutes in this Williamsburg precinct during a presidential election then at least 4-5 poll workers to check in voters and 12-15 voting booths or machines are needed. Data on the number of voters that arrive per hour and the amount of time it takes to check in and vote are often collected by the state or by certain polling places. A general, free version of this discrete-event simulation was created in Java. This resource allocation tool takes previous data as an input and estimates the number of voting booths and staff needed in order to keep approximately 99% of wait times less than 30 minutes. Simulation and statistical analysis are used to determine the number of resources necessary.**

Index Terms – data analysis, elections, public policy, simulation

INTRODUCTION

After many voters waited hours to vote in the 2012 election, the Obama Administration created a Bipartisan Commission on Election Administration to investigate Election Day problems and work on decreasing lines at the polls. The commission declared that no citizen should wait more than 30 minutes to vote [1][2]. In 2012, two-thirds of voters waited less than 10 minutes to vote, and only about 3% of voters waited over an hour. However, the average wait time for those 3% of voters was almost two hours, and about 12.5% of voters (over 16 million people) waited over 30 minutes. Therefore, the Commission aims to improve wait times for around 12.5% of American voters [3].

The reason why long lines form is because more people are arriving than can be served in a certain window of time. There are three general ways to reduce queue lengths: reduce the number of people arriving at once, increase the number of servers and resources, or decrease the length of time the service takes [3]. In this case, the servers and resources are the poll workers and the voting booths, and the service time is the time it takes to check a voter in and the time it takes a voter to vote. This paper will address the second method of decreasing queue lengths and wait times, which is to adjust the number of servers. A polling location cannot influence when voters arrive, but can influence how many poll workers to hire and voting booths to buy. However, with proper training poll workers can also decrease the time it takes to check voters in, and they can even decrease the voting times by handing out sample ballots while people are waiting in line.

One of the sources of long queues is a lack of resources available per voter. One way to measure this cause of long wait times is to investigate the number of voters served per polling place and served per voting booth or machine. A 2004 survey by the United States Election Assistance Commission reported that the average precinct size was around 1,100 people, though some precincts can be significantly smaller or larger depending on location [4].

Some states, including Virginia, have laws that restrict the maximum size of precincts. By Virginia law, no precinct can be created with more than 5,000 registered voters, and if in any presidential election more than 4,000 voters vote, the precinct must be redistricted [5]. However, not all states have such restrictions. For example, some precincts in Florida have as many as 8,000 people, while others are closer to 1,000 [6]. This difference in precinct size often creates a wide variation in the number of voting booths or machines available to voters. The unequal availability of voting booths and poll workers, based on the budget available in each precinct or location, can cause wide variation in voter wait times within, and between, states.

Similarly, laws are often created on how many voting booths or machines a polling place must have per registered voter. In Virginia, by law there needs to be at least one voting booth or machine for every 750 registered voters [7]. In some states this ratio is significantly lower. Pennsylvania sets a range of 300-400 voters per station, and Ohio recommends a ratio as low as 175 voters per station. However, in some states like Florida, laws like this do not exist at all, likely contributing to the extensive wait times seen in that state [6]. In an extensive nationwide survey, Florida was found to have the longest average wait times, with voters waiting on average almost 40 minutes. Other

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areas with problems include D.C (36 minutes), Maryland (36 minutes), Virginia (25 minutes), and South Carolina (25 minutes) [3]. A non-partisan 2014 study found that precincts with longer lines tended to have fewer poll workers, fewer machines, or fewer of both [8].

One of the worst problems with having extensive wait times is that these long queues turn away voters from the polls. A study conducted after the 2012 election stated that at least 200,000 Florida voters did not vote because the long lines they witnessed at the polls discouraged them. The analysis was based on precinct closing times and typical voter patterns, though the authors suspect that the number of discouraged voters may have been significantly higher [9]. In a closer election, these discouraged voters could have had a huge impact on the outcome of the election. Additionally, surveys suggest that voters who wait in line longer have less faith that their votes are being counted properly, leading to a decline in confidence in the electoral system [3].

Another problem with extensive wait times is that several studies have found that they tend to affect minority voters and urban voters more than other types of voters [3][8]. The nationwide 2012 survey on wait times found that white voters waited on average 12 minutes, while African Americans waited 23 and Hispanics waited 19 [3]. Studies also conclude that this difference in wait time is likely due to where minorities live, as white voters who live in diverse or urban neighborhoods also experience longer wait times [3][8]. These precincts tend to have more voters and so have fewer poll workers and voting booths available per voter. Additionally, one study found very low polling place compliance with state restrictions on the number of resources that are supposed to be available per voter in two of the worst states for lines: South Carolina (25% compliance) and Maryland (11% compliance) [8]. This lack of compliance with state laws perhaps contributes to the long wait times for urban and minority voters.

The Commission on Election Administration proposed a variety of simple fixes to this wait time problem including allowing citizens to register to vote online, expanding early in-person voting and mail-in voting, and allowing local officials to use any widely available technology not just limited and out-dated voting machines [1]. One of the Commission's suggestions is for election officials to test how long it takes an average voter to vote in order to determine how many poll workers, machines, and voting stations will be needed [2]. Because wait times are a problem in many parts of the United States, this study aims to use modeling and simulation analysis in order to ensure that almost all voters at any particular precinct will spend less than 30 minutes at the polls.

LITERATURE REVIEW

The current available research on wait times almost exclusively comes from survey analysis. The nationwide 2012 survey solicited responses from 200 voters in each state and D.C. for a total sample size of 10,200 voters [3]. However, surveying voters, especially days or weeks after an election, may not be a reliable indicator of actual wait times as voters may forget precisely how long they waited. Another 2012 study from the U.S. Government Accountability Office instead requested wait time data directly from jurisdictions and found that most jurisdictions did not collect data on wait times, perhaps indicating those precincts do not generally have wait time issues. Because most precincts did not have data, this study asked election officials if their jurisdictions had wait times that were too long. Different districts, however, can have different opinions on what length of time would be considered too long, with some districts thinking 10 minutes was too long and others thinking 30 minutes [10].

While most studies on wait times have relied on surveys, there have been some analyses that directly collected voter data or used simulation. In 2014, the Maryland General Assembly required the state and local boards of election to make sure voters could complete voting within 30 minutes. This study on wait times in Maryland had observers mark down how long it took voters to get to a voting machine, though simulation analysis was not used [11]. The same researcher who predicted over 200,000 voters were discouraged from voting in Florida in 2012 ran a simulation analysis to see if the extensive lines in Florida, with some precincts closing almost 7 hours after official closing time, could have been prevented [9]. Additionally, at Caltech and MIT a collaborative project titled "Voting Technology Project" was created after the 2000 election to evaluate the current state of the voting system in the United States. This project has been publishing papers and collecting data on voting patterns and lines and has also been preparing a tool to help polling places better allocate resources (vote.caltech.edu, web.mit.edu/vtp/calc1.html). This tool uses queuing analysis, rather than this paper's data and simulation analysis approach, in order to estimate the number of poll workers or voting booths needed. However, they use a constant arrival rate rather than a nonhomogeneous Poisson process (NHPP), which changes the rate throughout the day. An NHPP more accurately reflects increased demand for poll workers or voting booths during peak hours.

METHODOLOGY

The methodology associated with our analysis of the November 2015 elections in Williamsburg, Virginia is outlined in the three subsections that follow: the voting process, data collection, and data analysis. There were two check-in workers and seven voting booths during the day.

I. Voting Process

The Stryker Williamsburg polling location in Virginia was observed and data was collected during the off-year November 2015 delegate election. The polling location is set up like most other polling places across Virginia and across the country. A voter arrives and is greeted by a poll worker, and they then enter a check-in line. When a poll worker becomes available, that worker checks the voter's ID and compares it against the entries in their poll books to ensure the voter is a registered voter who is voting at the correct polling location. The voter then enters a line to vote. Once a voting booth becomes available, a poll worker hands them a paper ballot and they enter the voting booth. Once the voter has finished voting, they put their ballot through an optical scanner and then leave the polling location.

Williamsburg's Voter Registrar, Winifred Sowder, claims check-in lines and voting booth lines are where back-ups occur most often during a high turnout election [12]. Lines tend to be even worse at the voting booths rather than the check-in counters because people can take a few minutes to vote while checking an ID is generally quick. Long ballots have been shown to significantly increase voting times, especially if there are little known state-wide constitutional amendments or smaller elections on the ballot [9]. Lines almost never arise at the optical scanner unless there is a machine breakdown, as it takes only a couple of seconds to scan a ballot. If the machine does break, voters leave their ballots in a box on their way out.

Therefore, the most important staffing and budget decisions to investigate are the number of voting booths needed and the number of poll workers and poll books needed to check voters in. Poll worker pay varies significantly by locality. In Fairfax County, a wealthy suburb of Washington D.C., election officials are paid between $175-250 per day, while in the City of Williamsburg in Virginia, officials are paid $100 [13]. The poll books are sometimes on paper but often on computers, as in Williamsburg, and so the polling location would have to purchase extra computers as well. Similarly, cost varies for voting booths. Some polling locations use a desk and a cardboard box to create privacy, while others buy tall frames with curtains to act as their voting booths. Some decide to use expensive voting machines over paper ballots, which can cost thousands of dollars per machine. The City of Williamsburg claims their desk plus cardboard box voting booths cost no more than $50 per booth [9]. Buying voting booths plus the cost of printing out paper ballots is significantly cheaper than investing in voting machines.

Because the cost varies significantly from location to location, budget was not included in the simulation model. Voting is a public good and low wait times are in the best interest of everyone in a well-functioning democracy. The model instead attempts to find the minimum number of poll workers/books and voting booths in order to meet the recommendation that no one should wait over 30 minutes. The national average wait time is about 12 minutes and only 12.5% of people wait over 30 minutes**.** All states (except Florida, D.C, Maryland, Virginia, and South Carolina) have average wait times of less than 20 minutes [3]. Since the majority of the country is managing low wait times, the other states and polling locations should be able to as well.

II. Data Collection

Data was collected from the Stryker polling place at the Williamsburg Community Building on November 3rd, 2015. This precinct has slightly over 4,000 active voters and slightly over 5,000 if inactive voters are counted [14]. An inactive voter in Virginia is a voter that hasn't voted in at least two federal elections and appears to have moved their residency but has not confirmed their move. This election was an off-year election without a Governor's race that represents the lowest turnout general election in a four-year election cycle in Virginia. In Virginia, presidential elections recently have had turnout around 70-75% of registered voters. Governor's and congressional elections have around 40-45% turnout, and delegate elections are closer to 25-30% turnout [15]. While this election was a low-turnout election, data collected on how long voters take to vote is useful and can be used to predict lines in higher turnout elections. In addition, the pattern of arrival times to the polling place is likely to repeat itself from one election to the next.

The polling place was open from 6am to 7pm. Four types of data were collected: arrival times for all voters and check-in times, voting times, and departure times for a sample of voters. For every 15 or 20 voters, depending on how busy the polling place was at any given time, a stopwatch was used to time how long it took for that voter to be checked-in, how long it took for that voter to vote and scan their ballot, and the time that voter left. A total of 85 voters were sampled throughout the day at random. For a couple of these voters, some data points are missing due to the busyness of the polling place and the hectic nature of an election. All data referenced in this paper can be found at www.math.wm.edu/~leemis/polling/data/index.html. The collected data was analyzed and fitted to various probability distributions.

III. Data Analysis

Arrival rate. Because the arrival rate varied throughout the day depending on the time of day, the arrival rates were modeled using a nonhomogeneous Poisson process. A count method to calculate the arrival rate was used to simplify the process, especially because precise arrival times were difficult to capture using just one poll observer. The arrival rate was changed every 30 minutes based the number of people arriving to the polling place per minute in that half an hour. If, say, 60 people arrived in a 30 minute timespan, the arrival rate would be 2 people arriving per minute. A 30-minute time span was chosen because a 15-minute time span occasionally only counted 10-20 people arriving, and the variation every 15-minutes may be due more to sampling variability than time of day.

Check-in times: A total of 85 check-in times were collected. Using the R package *fitdistrplus*, which fits data to parametric distributions, the method of maximum likelihood estimation was used to estimate parameters for the gamma, weibull, and lognormal distributions. Because the minimum time to check a voter in was 16 seconds, the distributions were fit to the data shifted over by 15 seconds in order to create a better fit. Three goodness-of-fit statistics were computed: Kolmogorov-Smirnov, Cramer-von Mises, and the Anderson-Darling. The gamma fit had the lowest test statistic value regardless of test. The distribution of check-in times, X, at this polling location is therefore modeled by a gamma distribution parameterized by a shape parameter κ and a rate parameter λ:

$$X \sim 15 + \Gamma(\kappa=2.8777, \lambda=0.1285) . \quad (1)$$

Voting times. A total of 83 voting times were collected. The voting times include the entire time a voter has their ballot in their possession, from receiving the ballot and voting in a voting booth to placing the ballot in the optical scanner. Because the time it takes to scan the ballot in the optical scanner is negligible, the voting time represents how long each voting booth is busy or in use for each voter. Using the R package, *fitdistrplus,* which helps fit data to parametric distributions, the method of maximum likelihood estimation was used to estimate parameters for the gamma, weibull, and lognormal distributions. Because the minimum voting time was slightly over a minute, the distributions were fit to the data shifted over by 60 seconds in order to create a better fit. Three goodness-of-fit statistics were computed: Kolmogorov-Smirnov, Cramer-von Mises, and the Anderson-Darling. The gamma fit had the lowest test statistic value regardless of test. The distribution of voting times, X, is therefore modeled by a gamma distribution parameterized by a shape parameter κ and a rate parameter λ:

$$X \sim 60 + \Gamma(\kappa=2.5677, \lambda=0.03739) \quad (2)$$

Total time in system. Departure times were collected in order to calculate voter total time in system. A total of 81 total times in system were collected. The average total time in system was 3 minutes and 50 seconds, or 230 seconds. The average amount of time checking in and voting accounted for only 163 of those seconds on average, leaving 67 seconds unaccounted for. This extra minute or so in the system includes any time spent in a queue but also the time it takes to walk from the entrance to the check-in line, from the check-in line to the voting booths, and from the optical scanner out of the building. Specific data was not collected on these short delays, only on check-in times and voting times. The average total time in the system of about 230 seconds was used as validation of the model.

VERIFICATION AND VALIDATION

A discrete-event simulation model with two multi-server queues–one queue representing the check-in line and one representing the voting line–was coded for the Williamsburg polling place in SIMAN/Arena. The simulation used the data collected from the 2015 election, including arrival rates, check-in times, and voting times. This model was later transferred to Java to create a web-based tool available to all precincts with their own data. Both the SIMAN and Java models output similar results for the same input.

Five replications of the SIMAN code were run, and the model found roughly the same number of people arriving (1,392) and around the same total time at the polling place (almost 4 minutes), validating the model. Table I shows the number of voters, the average total time in system per voter, and the maximum total time in system for any voter averaged over the five replications.

TABLE I
NOVEMBER 2015 SIMULATION RUNS

	Number of Voters	Average Total Time in System (seconds)	Maximum Total Time in System (seconds)
Average of 5 runs	1392.8	209.5	470.2
Actual data	1392	230	540

The 20-second difference between the actual average total time and the simulation average total time can be due to observer error or the walking that occurs between the check in station and voting booths. Occasionally voters stopped to chat with someone or stopped to get their "I Voted" stickers. In addition, the poll observer took breaks throughout the day so "total time in system" samples were not necessarily taken during each hour as the arrival rate was changing. The data collected on Election Day was used to validate the simulation model. The simulation output is similar to the collected data, indicating that the model is a good representation of the polling place on the 2015 Election Day. Additionally, an animation of the model was created in order to help verify that the coded model was meeting the specifications of the planned model.

RESULTS

The simulation was then run for a predicted high turnout presidential election such as the upcoming November 2016 election. Two methods for predicting turnout were used. In the first, the arrival rate for a presidential election was estimated at almost three times the current arrival rate. (Historical turnout percentages were taken directly from Virginia's election website) [14]. In the second method, sparse data from the Williamsburg Voter Registrar's office on turnout in 2012 was used for this estimate in case turnout patterns themselves are substantially different in different types of elections (for example, 2015 vs. 2016). For a high turnout election, the number of poll workers and number of voting booths need to be determined. While more resources are always better, a precinct cannot feasibly have 100 poll workers or 100 voting booths. Therefore, the goal for the simulations predicting 2016 wait times was to find the minimum number of resources needed (poll workers/books and voting booths) to ensure the maximum wait times are less than 30 minutes with a high degree of certainty.

I. Predicting November 2016 – Method 1

For the first method, the arrival rate found in November 2015 was multiplied by 2.75. Voter turnout in the Stryker precinct in November 2015 was 1392 voters or 26.8% of all voters (including inactive voters) [15]. Since the 2016 election will be a contested presidential election with no incumbent running, voter turnout will likely be more similar to 2008 than 2012. While the Stryker precinct generally turns out at a slightly lower rate than the state average, if it did turn out at around 74%, the statewide 2008 voter turnout, the turnout would be around 2.75 times higher than the turnout in the November 2015 election. The number of voters this year, 1392, multiplied by 2.75 would yield 3828 voters. The simulation was run five times with the same nonhomogeneous Poisson arrival process that was found in 2015, except the arrival rate of voters arriving in any given interval was multiplied by 2.75. If the exact same set-up were used as was used in the 2015 election (2 poll workers and 7 voting booths), the average wait time for the roughly 3800 voters would be close to 4 hours over five replications. If sufficient voting booths are allowed (15+) but only 3 poll workers are used, the average wait time is around 45 minutes and the maximum wait time around an hour and a half, still too high. Therefore, 4 poll workers were used and the number of voting booths was varied.

Table II shows the average total time in system for a voter and the maximum total time in system for any voter as a function of voting booths when 4 poll workers are used. The second and third columns are averaged over the five replications.

TABLE II

NOVEMBER 2016: METHOD 1 RESULTS WITH 4 POLL WORKERS

Number of Voting Booths	Average Total Time in System (minutes)	Maximum Total Time in System (minutes)
9	94.59	183.91
10	53.80	107.43
11	27.65	59.84
12	**8.71**	**28.98**
13	4.37	12.81
14	4.00	12.29
15	3.96	13.98

At least 12 voting booths are needed to ensure that the maximum total time in the system does not exceed 30 minutes. Increasing the number of voting booths from 9 to 12 decreases the average wait time from 1.5 hours to less than 10 minutes, and decreases the maximum wait time from over three hours to less than 30 minutes.

II. Predicting November 2016 – Method 2

Observing the sparse arrival data from the 2012 election, it is apparent that the arrival rates are slightly different throughout the day in the 2012 election compared to the 2015 election. In 2015 there was a peak in arrivals before and then right after lunch while in 2012 there was a peak before lunch but also a large peak in the early morning before work. This result is in line with what the Williamsburg election officials have said about high turnout in the early mornings during a presidential election [9]. Perhaps a peak election year attracts different types of voters from an off-peak election year, including voters who may work more time-restricted jobs and need to vote in the early morning. Therefore, just multiplying turnout by 2.75 as in the previous section may be an erroneous assumption. Because of the difference in arrival rates from an off-year election to a presidential election, it may be beneficial to use turnout from 2012 to predict how many poll workers and voting booths are needed in 2016.

The simulation was run five times with the same nonhomogeneous Poisson arrival process that was found in the 2012 data. Since only around 3200 voters voted in the 2012 election and likely the 2016 election will have closer to 3800 voters, turnout was multiplied by around 3800/3200 = 1.19. This simulation will expect around 3800 voters, or roughly 2.75 times as many voters as in the 2015 election.

If the same set up were used as was used in the 2015 election (2 poll workers and 7 voting booths), the average wait time for the roughly 3800 voters would be almost 5 hours over five replications. If sufficient voting booths are allowed (15+) but only 4 poll workers are used, the maximum wait time is still over 40 minutes. Because of the heavy peak traffic in the early morning, 4 poll workers is not enough to keep the traffic moving even with a sufficient number of voting booths. Therefore, 5 poll workers were used and the number of voting booths was varied.

Table III shows the average total time in system for a voter and the maximum total time in system for any voter as a function of voting booths when 5 poll workers are used. The second and third columns are averaged over the five replications.

TABLE III

NOVEMBER 2016: METHOD 2 RESULTS WITH 5 POLL WORKERS

Number of Voting Booths	Average Total Time in System (minutes)	Maximum Total Time in System (minutes)
9	141.24	207.44
10	90.90	149.61
11	53.80	100.54
12	31.78	73.91
13	17.65	52.09
14	9.39	39.19
15	**6.08**	**24.73**

About 15 voting booths are needed to ensure that the maximum total time in the system does not exceed 30 minutes, though only having 14 voting booths already brings down the average and maximum times substantially.

Comparing these two methods, it is clear that the non-constant arrival rate makes a substantial difference when planning how many poll workers and voting booths are needed. The second method indicates that perhaps arrival rates for different types of elections differ and that when planning resource allocation for a presidential race, polling locations should use previous presidential turnout patterns rather than off-year election turnout patterns.

TOOL CREATION

This simulation has been turned into a website in which a user can input their own data. This Java-based website that can be found at www.math.wm.edu/~leemis/polling/index.html. The simulation estimates the number of resources necessary to meet the federal commission's recommendation that no voter wait over 30 minutes. While Williamsburg is already appropriately staffed and has enough booths for the upcoming presidential election, many polling locations across the country have had long voter wait times in the past. Data on the number of voters that arrive per hour and the amount of time it takes to check in and vote are often collected by the state or by certain polling places. Hourly arrival data is entered, and a nonhomogenous Poisson process models the arrivals. Check in times and voting times are either defaulted if the polling location does not have data, or the user enters data values. Various fits can be chosen to fit the user's data including the normal, weibull, gamma, and lognormal distributions.

This tool takes historical data as an input and estimates the number of staff and voting booths needed in order to keep about 99% of wait times less than thirty minutes over the course of an election day. A greedy algorithm picks the lowest number of poll workers/books and booths needed.

CONCLUSION

Excessive voter wait times are a problem in some areas of the United States. These wait times not only waste voters' time, but can also discourage people from voting in general. A simple way to lower wait times is to have more poll workers and voting booths per polling location. A model was created in SIMAN and then in Java to analyze the recent 2015 election in Virginia as well as to predict wait times in the 2016 presidential election. Two methods for predicting turnout in 2016 were used: extrapolating turnout from 2015 data and predicting turnout from sparse 2012 data. Some assumptions that were made could lead to errors in the model. Extrapolating turnout from 2015 may not be appropriate if voter patterns differ from year to year. Predicting turnout from 2012 data also may cause some error, as the data was sparse. To compensate for potential error, voter turnout in 2016 in this model was set very high similar to 2008 levels.

The analysis suggests that for precincts similar in size to those in Williamsburg, which is expecting almost 4,000 voters in a worst-case scenario, that at least 4-5 poll workers and 12-15 voting booths are needed to maintain a reasonable average wait time (10 minutes) and maximum wait time (30 minutes). According to the Voter Registrar of the City of Williamsburg, these suggestions are similar to the number of check in stations and voting booths Williamsburg used in the last presidential election with short average wait times, further validating the model [9]. More precincts in Virginia should follow the City of Williamsburg's lead. Because most polling locations of this size likely already have between 7-10 election officials, requiring 4-5 of those poll workers to check in voters during peak hours is doable. However, the suggested number of voting booths for a presidential election, 12-15, is significantly higher than the 7 booths used in this past election in Williamsburg. For precincts that use paper ballots rather than expensive voting machines, investing in voting booths is fairly cheap.

This analysis has shown that it is possible to significantly reduce voter wait times by investing in voting booths and staffing appropriately. Even adding just one or two additional voting booths in a precinct with long lines can drastically reduce voter wait times. A tool was created for predicting poll worker and voting booth needs in other polling locations. With the insight gained from this tool, it is possible to have almost everyone vote in less than 30 minutes if proper staffing and booths are made available.

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