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WHAT QUEUING THEORY SAYS ABOUT MANAGING POLLING PLACES AMID COVID-19

STANFORD-MIT
PROJECT ON A
HEALTHY ELECTION

ACKNOWLEDGMENTS

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ABOUT THIS REPORT

The findings, interpretations, and conclustions expressed in this report do not necessarily represent the views or opinions of the Massachusetts Institute of Technology or Stanford University.

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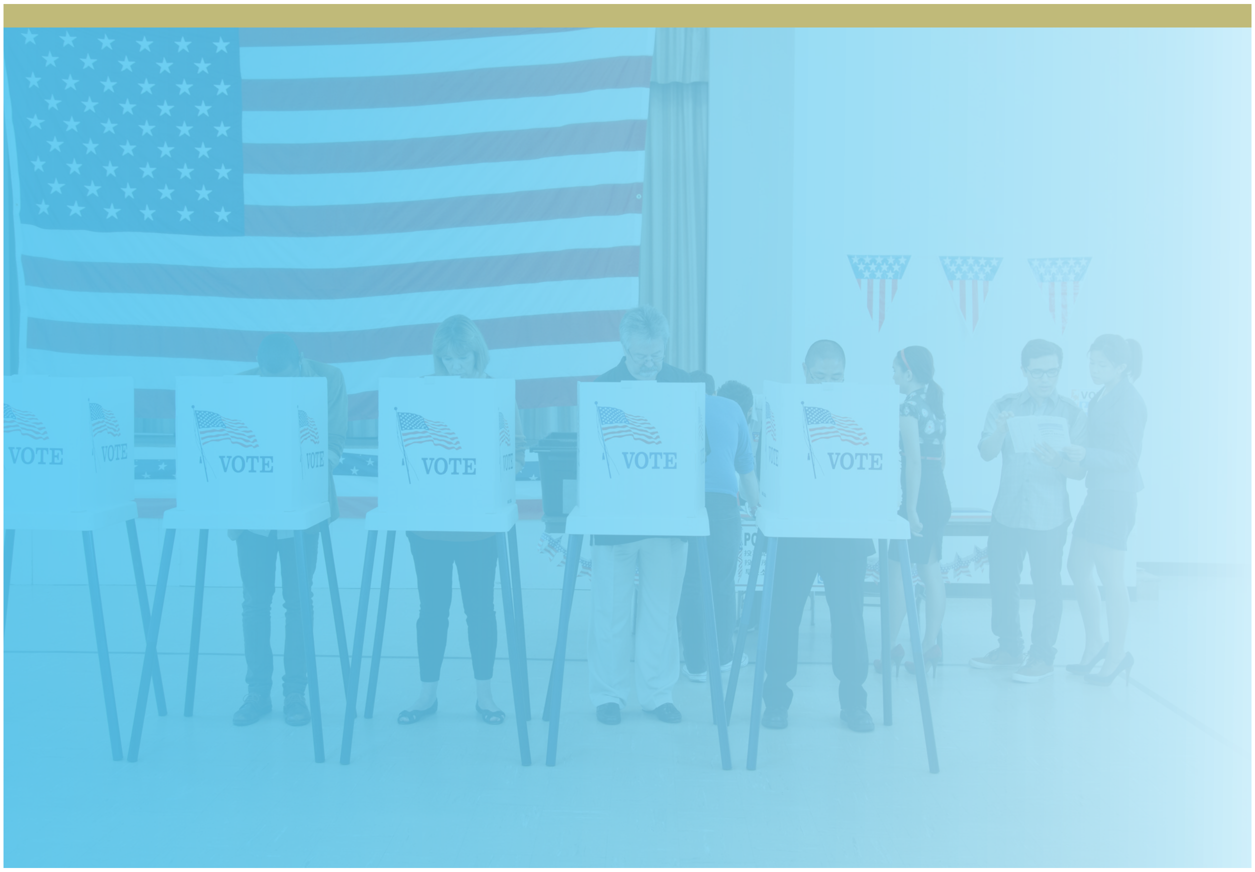
CONTENTS



INTRODUCTION

Managing how Americans vote in 2020 is one of the greatest challenges facing the nation. If the voting environment is unsafe, the risk of spreading infection from the act of voting is real. If the voting environment is perceived as being unsafe, voters may not come to the polls.

A general consensus has emerged among the broader elections community that providing a safe voting environment starts by allowing any voter who wishes to vote by mail to do so. This would reduce the number of voters in confined spaces, either on Election Day, or during early voting periods before Election Day. Achieving an increase in voters balloting by mail is recognized by all as being a steep logistical challenge, requiring the reallocation of resources and redesign of procedures at a pace never before seen in the history of American elections.

Even if large numbers of voters choose to vote by mail--current estimates range from 50 to 70 percent of voters--in-person voting will still be necessary. Some voters will need to vote in person. In-person voting can serve as a failsafe for those who have been unsuccessful in navigating the mail-ballot route. In states with Election-Day registration, it may be the only way some new voters can participate. For others, with certain disabilities or in need of assistance, a physical polling location will also be a necessity. Many voters will decide at the last minute to vote, and may be unable to navigate the vote-by-mail system before Election Day.

Other voters will choose to vote in person, despite the risks. Some distrust the postal service or feel a sense of civic duty that can only be fulfilled in person. Some voters may vote in person due to a perception that mail balloting is a source of voter fraud.

Designing polling places to serve these voters will be a logistical challenge, perhaps as great as the one to rapidly expand access to mail balloting. The challenge starts with retaining polling places and poll workers. Senior centers are out as polling places, and perhaps schools and churches, too. Poll workers themselves have proven difficult to retain in this environment. Most poll workers are over 60 years of age and a quarter are over 70, putting them at the core of the most-vulnerable population to the COVID-19 virus.

Even when procuring facilities and poll workers is not a challenge, designing and managing the polling places will require a redesign of physical places and operating procedures. To maintain social distancing, poll booths will need to be placed further apart. Poll workers will need to be spaced apart from each other, and their work stations or processes will need to be designed so that they can assist voters safely. It will take longer to check in voters and to mark and scan ballots, as sanitation routines will slow down the routine tasks that define the voting process.

For election jurisdictions of all sizes, planning to make all the changes necessary to vote in 2020 can be an overwhelming task. Plans that have been fine-tuned over the course of decades have to be rethought, often from scratch. Election officials are not alone in this planning task, however. Academics and members of the civic tech community have developed tools to help election officials plan for these changes, and for the public to understand the changes that are necessary to be made. The website of the Stanford-MIT Healthy Elections Project (HealthyElections.org) provides a portal to many of these tools.

This white paper focuses on one important aspect of managing the redesign of polling place procedures to accommodate the realities of voting amid the pandemic: managing the volume of traffic through a polling place. It discusses how queuing theory can be harnessed to provide guidance about questions such as these:

- How many voting booths, check-in stations, and scanners do I need to handle anticipated turnout?
- How long are the lines I should anticipate during the day?
- If I have to limit the number of people in the room where voting occurs, how many people are likely to be waiting outside to vote?

Questions such as these become more critical given the particular challenges of managing crowds on account of social distancing practices. One particular dynamic that will be more prevalent is managing bi- or trifurcated queues.

A commonplace example is where a small number of customers are allowed inside a store and line up at the cash register (Queue 1) while a (perhaps longer) line forms outside waiting for someone to leave so that they can go inside (Queue 2). Given the way that the COVID-19 virus spreads, and the fact that polling places can attract large numbers of people to a building that may not normally attract such levels of traffic, knowing how many people may be congregated outside waiting to vote, perhaps stretching down the street and around many city blocks, will be critical information for election and other officials to plan for.

Similarly, the need to limit the number of people waiting for a voting booth or scanner to open up may create two or three lines inside a voting facility where no lines used to form.

The remainder of this paper addresses these topics:

- The applicability of queuing theory to the problem of managing polling place lines and capacity.
- A refresher into the application of queuing theory to polling place management.
- How queues (lines) might change with COVID-19.

Included in the text below is a case study based on recent research into how polling places operate.

A REFRESHER ON WHAT WE KNOW

This white paper builds directly off of a previous report, *Managing Polling Place Resources*, which was released by the Caltech-MIT Voting Technology Project in 2015, in response to the long lines that beset the 2012 presidential election, and the work that followed to reduce the likelihood that such lines would arise again. That report provides an accessible overview of queuing theory and its application to polling places. Readers unfamiliar with that short report are encouraged to consult it. Here, we touch on the six main takeaways from the report, and note how those takeaways apply now in light of COVID.

1. *Long lines are not ubiquitous, either across time or space.*

This fundamental result will still hold, though an updated set of expectations and proper planning will be needed to ensure that the problem does not become worse this November.

2. *Where long lines do occur, they are costly, in terms of lost votes, confidence in elections, and time spent by voters.*

During this pandemic, long lines are especially costly as they will increase the voter's exposure to infection, especially when lines are inside.

3. *Long lines occur in predictable places on a chronic basis — in a small handful of states, in urban areas, during early voting, and in areas with many non-English speakers.*

Similarly, the COVID-19 pandemic is disproportionate in its impact, impacting the elderly, infirm, and communities of color disproportionately severely. These two factors could combine in unfortunate ways to disproportionately impact certain demographics.[1]

4. *Long lines are fundamentally due to a mismatch between the number of voters who show up and the resources available to accommodate them; insights from queueing theory provide reliable guidance about how to minimize this mismatch.*

Queueing theory can also help determine a safe, practical setup for polling places that allows for efficient and safe waiting procedures.

5. *A few localities already provide models of best practices that are addressing voter-election resource mismatches.*

Unfortunately, we do not have nearly as much data about voting during a pandemic. Crucial measures of resources and voter behavior are expected to differ significantly from previous years. Lessons from primaries between March and November can be informative.

6. *An important first step in addressing long polling place lines is for local jurisdictions to get into the habit of regularly collecting the data necessary to diagnose the presence of congestion and analyzing it in a way that helps them to allocate the resources they have, or to advocate more effectively for new resources.*

[1] For an early example, see the Healthy Elections Project's work surrounding the April 2020 Wisconsin Primary and poll closures in the Milwaukee area

This point, perhaps more than ever, is true. In order to make informed decisions about the general election, understanding voter behavior and queuing dynamics during the pandemic is crucial.

QUEUEING BASICS

Long lines occur when resources are inadequate. Yet, resources are always constrained, especially in election administration. Thus, managers must decide how best to allocate scarce resources to get the best overall performance. Tools that are based on the science of queueing theory can help managers understand the various trade-offs involved in allocating resources and make the tough decisions that face them.

The queueing system is composed of three parts: (1) the arrival of users, (2) the queue itself, and (3) the service that users receive. This is illustrated in the figure below.

To understand a system like this, we need to answer the following questions about each part of the queuing system:

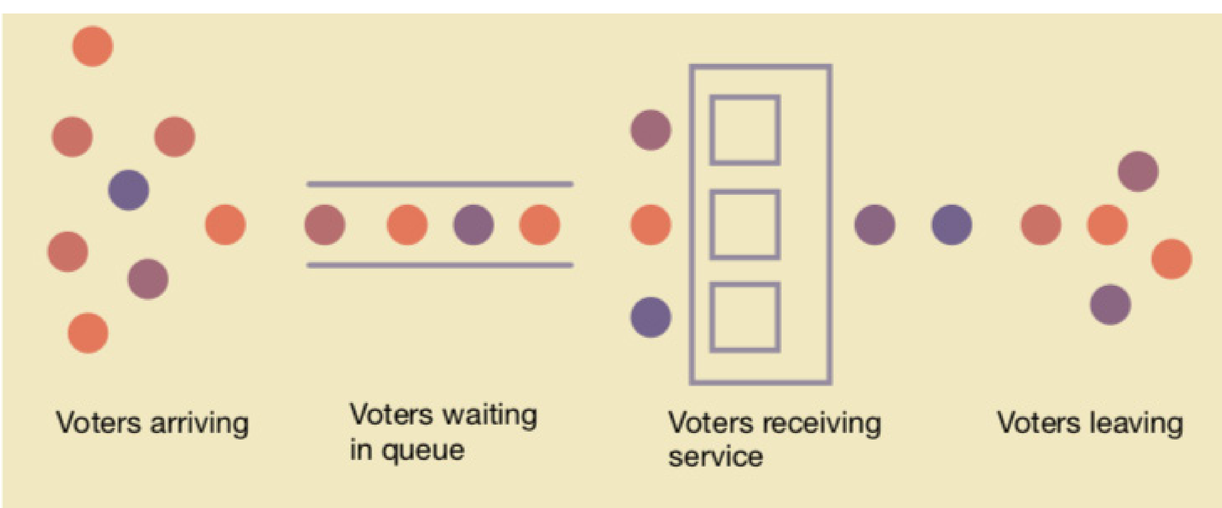
» **Arrival of voters:** At what rate do voters arrive, and how variable is the arrival process?

» **The queue itself:** How do voters wait for service? For instance, do voters queue in the order of arrival so that the first users to arrive are the first to be served? And are there multiple queues, one for each server, or just a single queue that feeds a set of parallel service stations?

» **The service that voters receive:** How many service stations are available to receive voters, how quickly are voters processed, and how variable is the processing time?

Many of the fundamental lessons of queueing theory depend upon simple characterizations of the arrival and service processes, in terms of average rates and the level of variation. The existence of variation of any kind will render the same result: queues grow non-linearly as the demands placed on the system increases.

As a simple example, imagine a one-step voting process where there is a single station, and once at the front of the line, the voter can vote in an average of six minutes, at which point the next voter can vote. This means on average, a maximum of ten voters per hour can vote. This rate is called the **throughput**, or the capacity of the system. As the arrival rate approaches this capacity,



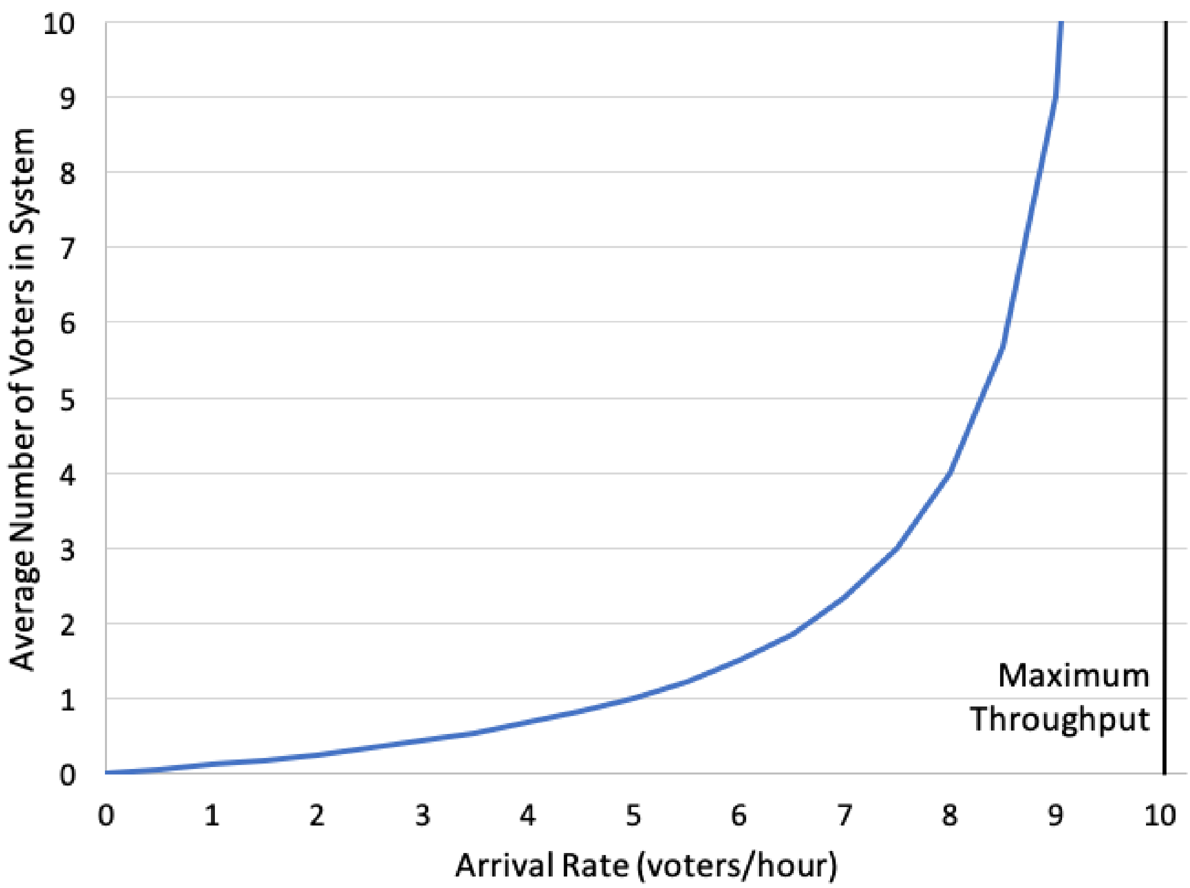
the number of people expected to be waiting in line (or voting) increases exponentially. Increasing the hourly arrival rate from about 5 voters to 7 voters increases the average number of voters at the polling place from 1 voter to 2 voters. When the hourly arrival rate increases from 7 voters to 9 voters, there is a much larger increase in the line length: the average number of people at the polling place from 2 to 9 people.

APPLICATIONS TO A VOTER QUEUES

Indeed, the average number of voters increases without bound as the arrival rate approaches the capacity of the system (10 voters/hour). This limiting behavior is seen in all queueing systems, but can be complicated by other factors. Here we discuss a few key terms when considering voting systems.

A **multi-step process** has more than one distinct server-customer relationships and therefore more than one place a customer could wait (while waiting for an open server). A polling site will have multiple steps, depending upon the voting method. For instance, if voting is on paper ballots, then a site might have three steps: check in, ballot marking or voting, and check out, with ballot scanning or submission. While a check-in step may itself have multiple steps (like ask questions, then find address, then give ballot), these will be performed by one poll worker for one voter, so we typically consider check-in as one server-customer relationship and therefore one step.

The **bottleneck**, or rate-limiting step, is the step within a multi-step process with the smallest capacity (or lowest throughput). A



bottleneck cannot be eliminated entirely, only moved to another step in the process. For a purely sequential process like voting on election day, we expect the longest lines to form directly prior to the bottleneck. If the other steps in the process have significantly higher capacities (see example below), we expect that the only lines will be at the bottleneck. Because a bottleneck cannot be eliminated, it is best practice to plan which step will be the bottleneck. It is often good practice to make check-in the bottleneck, because it is the most resource-intensive step in the process, and because it is the first step in the process. We then expect to have just a single line prior to check in, and voters will only wait there.

With this terminology in mind, here are four general strategies to make lines shorter at polling places without fundamentally changing the multi-step process:

» **Decrease the arrival rate.** While limiting voting is antithetical to democracy, increasing the number of polling places, expanding the number of early voting days and/or the length of the voting day, or encouraging mail-in ballots are ways to decrease the arrival rate at a given polling place.
» **Increase the number of servers a*t the bottleneck.*** Adding more poll books and workers to the check-in station, if the bottleneck is the check-in step. Alternatively, we can increase the number of voting booths or machines if the bottleneck is at the balloting step. If we increase the number of servers significantly, the bottleneck might shift to another step. Consider a small polling place with one voting booth and one check in station, with the voting booth the bottleneck. Adding a second voting booth may help, but a third voting booth might have minimal impact if it shifts the bottleneck to the check-in step.
» **Decrease the service time** *at the bottleneck.* Investments in training, simpler processes, and automation are all tools that may help decrease service times. Focusing these efforts to improve the bottleneck step is crucial. An easier-to-read ballot will improve the throughput of the voting step, but won't help lines if check-in is the bottleneck. Similarly, if service time is significantly reduced, the bottleneck may shift to a different step, making further improvements less valuable.
» **Decrease service and arrival time variations.** When service times and arrival rates vary significantly from voter to voter, lines increase. An example of service-time variation is when voters needing to complete a provisional ballot application join the same line as voters who have a traditional registration. A bus load of voters arriving all at once is an example of arrival-time variation.

Many polling sites experience time-of-day variation in voter arrivals. The arrival rate is much higher at the start of the day, and possibly later in the day, after the work day. The amount of queueing increases non-linearly with the arrival rate, and thus, this variation increases the average wait time experienced by a voter. Anything that could level the arrival rate over the day will reduce the amount of queueing. For instance, encouraging non-working voters to come during off-peak times would help.

The time to check in or to vote can also exhibit harmful variation. Sometimes this variation is due to equipment malfunctions: equipment needs to be maintained and prepped for election day, and there should be provisions in place to react to any equipment failures, if they should occur. Another source of variation are "exceptional voters" who require much longer service times either to check in or to vote. This might be because they are not in the pollbook, or they need help in executing the vote. In any event, the site should have protocols for handling such voters in a way that respects their requirements and needs, and does so in ways that minimizes the disruption of the normal flow of voting. For instance, a site might have a dedicated resource that is available to help with these exceptional cases.

HOW QUEUES MIGHT CHANGE WITH COVID-19

Voter queues will look and behave differently with social distancing in mind. Above, we discussed the four fundamental ways to change a queue's length, all of which will be impacted by social distancing: 1) change the arrival rate of voters, 2) change the number of poll workers, 3) change the service time, 4) increase variability, especially of service times. Additionally, there are logistical considerations about multiple people being at the same place at the same time, and additional steps it may be beneficial to add to the process.

SPECIAL CONSIDERATIONS

In order to best maintain social distancing, many jurisdictions have seen their typical polling place plans completely upended. Schools, firehouses, churches and other civic spaces have closed or otherwise been unable to safely host a polling place. Some traditional places may simply be too small to safely fit enough people inside. In Kentucky, each county opened only one polling place, often in a suitably large venue such as a convention center or Division-I football stadium, but this still caused knock-on effects such as limited parking and heavy traffic, which are often thought of as queues themselves.

Line management, in addition to line length, will also become a factor. No matter the size of the polling place, each room will have a maximum number of people who can be suitably distanced within the room. A finite room capacity will mean that if a line grows too long, it will stretch outside. While previous elections have seen lines stretch around the block, election planners may need to procure additional waiting areas where voters can remain suitably distanced, and potentially protected from the elements.

CHANGES IN ARRIVAL RATE

There are many factors which will impact the arrival rate of voters, with lower voter arrival rates likely to lead to shorter lines. Without intervention, we have seen polling places close and consolidate (as in Milwaukee in the April Wisconsin primary) which will lead to higher voter arrival rates. Policies that could reduce voter arrival rates include: expanded early voting, extended voting hours, additional polling places, and expanded absentee voting.

Finally, decreasing the time-of-day variation in arrival rate will lead to a reduction in lines. Policies like a pre-assigned time or an appointment system would do this in theory but may be too logistically difficult to pull off in practice. A state or federal holiday would likely help to spread the morning rush more evenly over the course of election day, but we have not studied this impact in detail.

CHANGES IN NUMBER OF SERVERS

In 2020, polling places may need to limit the number of servers at each step to keep people separated, and jurisdictions may struggle to hire poll workers.

Poll workers may be more reluctant to work on this coming election day relative to the past. A significant number of poll workers are elderly and susceptible to severe health risks with COVID-19. Jurisdictions from Alaska and North Dakota have reported struggling to retain and hire poll workers.

Polling places will need to ensure people are spaced out. Each check-in station may need to be its own table, spaced from adjacent tables. There may be space limitations on how many stations can fit into a room. Voting booths themselves may also need to be eliminated. A traditional bank of voting booths has an approximately 2 foot wide booth. In order to maintain distancing, two out of every three booths will need to be blocked if each voting booth can not be individually placed. Round desks with multiple people huddled around a portion will similarly cause a reduction in booths.

CHANGES IN SERVICE TIME

We expect the service times, both for the time to check in and the time to vote, will increase in 2020. There will be additional time needed for public health screening, and for cleaning the equipment and booths. There may also be longer service times due to less experienced poll workers, as a number of new workers will be needed to make up for the anticipated shortages.

If voters need to be asked about COVID symptoms, have their temperature taken, or any number of other steps, the time to check in may increase. If a polling place does not plan for this increase, long lines may form. It may be beneficial to add in a pre-check in step where poll workers ask voters in line about symptoms. These tasks will need to be tested to understand where in the process the bottleneck will be. Similarly, officials must account for time increases due to both voters and poll workers being unfamiliar with a new process.

In its June 2020 primary, Georgia noted it struggled to retain previous poll workers, leading to untrained people working the polls, increased service times, and therefore long lines. Even if well trained, a new worker (or a seasoned worker going through a new process) who checks in voters 10% slower during the first few hours may significantly exacerbate long lines in the early morning.

CASE STUDY: HORACE MANN ELEMENTARY SCHOOL

Horace Mann Elementary School is a fictional, typical elementary school that hosts a polling place on Election Day. A reasonable elementary school gymnasium is about the size of a small basketball court (84' x 50'), so we will consider a room with 5,000 sq ft. We will assume that this polling place expects to serve 1,500 voters on Election Day with polls open for 12 hours for an average rate of 125 voters per hour.

Horace Mann Elementary operates in a county with a three-step voting process: check-in, voting on paper in voting booths, and scanning the ballot. During previous presidential election years, Horace Mann has operated a busy polling place, but one that has rarely seen long lines. The workers have set up stations such that short lines would sometimes form prior to check-in but voters almost never waited longer than 30 minutes. See Table 1 for a example data relating to their voting process.

Using the M/M/k queueing model detailed in the previous whitepaper, we expect this system to have an average wait-time of 2.5 minutes, an average line of 5 people, and a near-zero chance of waiting longer than 30 minutes.

Now let's consider this system under social distancing measures for 2020. We first must estimate how many people will be allowed in the gymnasium at one time. There are two major ways to estimate this.

» Divide the area of the facility (after subtracting features such as tables and voting booths) by a spacing allowance for each person in the facility. For instance, guidance from the Colorado Department of Public Health and the Environment suggests 144 square feet per person, to give people space to both pass and maintain distance.[2] Before taking into account the space occupied by voting booths, tables, chairs, etc. in a 5,000-square foot gymnasium, this allowance works out to 34 people allowed

[2] Approximately the amount of space offices are zoned for: https://www.usfa.fema.gov/coronavirus/planning_response/occupancy_social_distancing.html

TABLE 1. SERVICE STATISTICS AT HORACE MANN ELEMENTARY SCHOOL

STATION NAME	NUMBER OF STATIONS	PROCESSING TIME (MINUTES/VOTER)	THROUGHPUT (VOTERS/HOUR)	AVERAGE UTILIZATION
Check-In	3	1.25	144	87%
Voting Booth	18	5	216	58%
Scanning	2	0.5	240	52%

in the gymnasium at one time. On the other hand, simply maintaining six feet of social distancing would require 36 square feet of space for each person at a minimum. (In contrast, a building code might allow 15 square feet per person, or over 300 people in the gym in normal times.)

- Draw a floor plan of the polling place to scale, taking into account the space occupied by the equipment, proper social distancing, and enough room for people to pass each other while staying properly distanced. This is a more involved method than the previous one, but can be especially useful to take into consideration the specific configuration of the polling place, and any space limitations that might further restrict the number of voters who may enter the room.

To keep this example simple, we adopt the first strategy, and pick a number in the middle, of 100 square feet per person.

In order to determine how many people will be allowed to wait in line inside and how that affects the line, we can use the Healthy Elections Queueing tool and a few assumptions. If we assume that 15 people will be in the room as non-voters (poll workers, administrators, security, observers), we are left with 35 voters allowed in the room. Of these 35 voters, we calculate that 3 check in stations, 18 voting booths and 2 ballot scanners means that 23 voters can be in the process of voting at once, leaving 12 spots for voters to wait in line. See below for a visual representation of how the 50 spots are allocated.

We can use the Healthy Elections Queueing tool[3] to see how this system would perform, assuming that the number of stations at each processing point and the processing time stays the same. Even though the average line length is only 5 people and there is room for 12 people inside, with this limited capacity line, there is an average of one person waiting outside the room, and the room will be full about 14% of the time. For the other 86% of the time, the voter queue will not exceed 12 people and fits inside the gymnasium. In order to accommodate these times of longer waits, we would recommend establishing a secondary waiting area for the 14% of time that an outside line will form.

OTHER CHANGES TO THE SYSTEM

It is unrealistic to assume that the voting process will stay the same, as discussed above. There are several things that will change with the voting process. Let us examine the impact when the following are incorporated:

- An additional 15 seconds of COVID-related questions are asked during check-in
- Only every third voting booth may be used to maintain social distancing
- Only enough poll workers show up to open 2 check in stations

If we use these factors to plan, rather than the pre-COVID-19 factors used above, here is what the service utilization picture looks like:

[3] http://healthyelections.org/queueing/

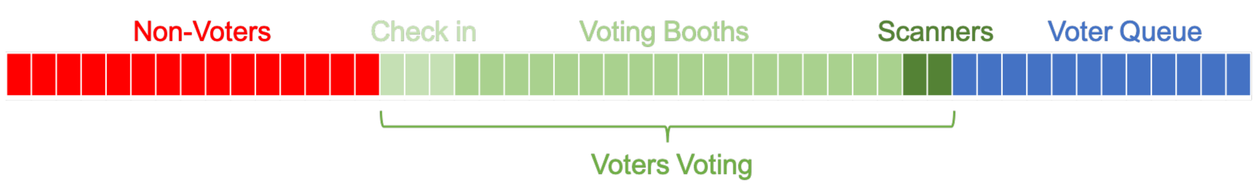


TABLE 2. REVISED SYSTEM WITH COVID-19 CHANGES				
STATION NAME	NUMBER OF STATIONS	PROCESSING TIME (MINUTES/ VOTER)	THROUGHPUT (VOTERS/HOUR)	AVERAGE UTILI-ZATION
Check-In	2	1.5	80	156%
Voting Booth	6	5	72	173%
Scanning	2	0.5	240	52%

Two key things have happened to this system in light of the COVID changes.

First, the bottleneck or rate-limiting step of the process has shifted. Originally, check in was the slowest step, meaning that lines were most likely to form prior to that step in the process. Now, the voting booth step has the slowest throughput and can only handle 72 voters per hour, while the check-in process can handle 80. Given the social distancing considerations, the polling site might not permit voters to wait between check in and the voting booths. Rather, when the voting booths are fully occupied, the check in stations will necessarily have to slow down and hold voters there until they can proceed to an open booth. Because of this interdependence, the check-in stations will operate with the same capacity as the voting booths, namely 72 voters per hour, and the voters would queue in front of the check-in stations Even though the bottleneck is the voting booths.

Second, the average utilization of the system at the bottleneck has gone above 100%. This is an indication that the system is unstable as the number of voters arriving per hour exceeds the system capacity. As a consequence, lines will continue to grow throughout the day and will only start to dissipate after the site closes and no additional voters can join the line. In order to fix this problem, every step in the voting process must have a throughput larger than the arrival rate (125 voters per hour). A simple (if not easily implementable) fix would be to open a second identical polling place and halve the number of voters going to Horace Mann Elementary. This would bring the average arrival rate down to 68 voters per hour, below the throughputs of both the check-in and voting booth steps, but may be unreasonable for a voting jurisdiction.

Outcomes such as these are the bane of any election administrator's existence. The glib answer under these circumstances is that the election official should take actions to restore the polling place to a situation where wait times are much shorter -- add check-in stations and voting booths, reduce the time it takes to check in, etc. The election official who is responsible for Horace Mann School may not be able to marshal the resources to return the polling place to a level of functioning that avoids an explosive growth in the lines. But, if the official has the opportunity to use a resource such as the Stanford-MIT queue length tool during planning, there is a greater chance that the needed adjustments can be made.

CONCLUSION

Election officials will undoubtedly face challenges during this election cycle that have not been as prevalent in the past. We believe that viewing these challenges through the lens of queueing theory can help bring to light the root cause of the problems, explain where resources are needed most, and simplify some of the decisions to alleviate these issues. Long lines may have slightly different causes during this election, but the best practices remain remarkably similar: accurate, conservative estimates of voter arrivals, service times, and staffing levels; efforts to improve service times and staffing levels at bottlenecks in the process; policies to reduce use of oversubscribed polling places; and policies to reduce variation within the process.

Other papers have detailed further challenges with this election such as the recruitment of poll workers and the closure of polling places. To the extent that election officials are able to surmount these challenges, analysis of the new operating plan using queueing theory will be crucial to ensure that polling places are safe and efficient, and that votes are counted accurately, quickly, and with an unshakeable perception of equality.

The 2020 election will present large scale operational changes across in person polling places and also in ballot counting processes. Queueing theory presents a way to model these untested systems and raise red flags that may increase wait times for voters and lead to significantly delayed results. Data gathered through primaries and trial processing runs will be able to inform queueing theory predictions and improve the efficiency and fairness of the election.

Gathering and analyzing these data will be a challenge, but it is one that can be met with resources that are already available to election officials. Even with the election fast approaching, it is not too late to apply these tools to the benefit of voters everywhere.

FURTHER READING

Below is a list of further readings that expand on the topics of this white paper.

Bipartisan Policy Center. Improving the Voter Experience. 2018. Report of a large-scale project to measure wait-times across scores of local jurisdictions in the 2016 election and apply queuing theory to the analysis.

Bipartisan Policy Center. The 2018 Voting Experience: Polling Place Lines. 2019. Results of the largest-ever observational study of polling place resource and wait times.

Richard C. Larson and Amedeo R. Odoni, Urban Operations Research, Prentice-Hall, 1981. Classic textbook in operations research available free online. Chapter 4 provides a straightforward introduction to queuing theory.

Floyd H. Grant III, "Reducing Voter Waiting Time," INTERFACES 10, no. 5 (1980): 19–25. Earliest published application of queuing theory to the problem of long lines at the polls.

Alexander S. Belenky and Richard C. Larson, "To Queue or Not to Queue?" OR/MS Today 2006: Brief, accessible discussion of queuing-related issues related to the problem of long lines at the polls.

Theodore Allen and Mikhail Bernshteyn, "Mitigating Voter Waiting Times," Chance 19, no. 4 (2006): 25–34. Illustrates how statistical techniques can illustrate and address problems of long lines at the polling place.

Douglas M. Spencer and Zachary S. Markovits, "Long Lines at Polling Stations? Observations from an Election Day Field Study," Election Law Journal 9, no. 1 (2010): 3–17. Reports results of a systematic study of wait times at 30 polling stations across three counties in the San Francisco Bay area during the 2008 presidential election.

William A. Edelstein and Arthur D. Edelstein, "Queuing and Elections: Long Lines, DREs and Paper Ballots," Proceedings of EVT/WOTE 2010 (2010). Develops a "Queue Stop Rule" that can be applied to prevent long lines at polling places.

Mauer Yang, Michael J. Fry, W. David Kelton, and Theodore T. Allen, "Improving Voting Systems through Service-Operations Management," Production & Operations Management 23, no. 7 (2014): 1083–1097. Develops methods to allocate voting machines optimally to precincts and presents a case study based on data from the 2008 general election in Franklin County, Ohio.

Xinfang (Jocelyn) Wang, Mauer Yang, and Michael J. Fry, "Efficiency and Equity Tradeoffs in Voting Machine Allocation Problems," Journal of the Operational Research Society 66: 1363–1369. Develops a technique to allocate voting machines that balances efficiency and equity in waiting times across a local election jurisdiction. Applies this technique to data from Franklin County, Ohio.

Charles Stewart III and Stephen Ansolabehere, "Waiting to Vote," Election Law Journal 14, no. 1 (2015): 47–53. Summary academic revision of white paper prepared for the Presidential Commission on Election Administration about long lines at the polls.

Robert M. Stein, Christopher Mann, Charles Stewart III, Zachary Birenbaum, Anson Fung, Jed Greenberg, Farhan Kawsar et al. "Waiting to Vote in the 2016 Presidential Election: Evidence from a Multi-County Study." Political Research Quarterly 73, no. 2 (2020): 439-453.

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