[[1]](#footnote-1)

Better Allocation to Reduce Voting Queue Length

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*Abstract*— Providing equitable voting experiences across voting precincts has been noted as an important goal in elections. We seek to provide equity to all voters so that no one particular group of voters is disadvantaged or disenfranchised. This paper uses the average absolute differences of waiting times across all precincts as a performance metric for equity. A simulation-based greedy improvement algorithm is proposed to generate machine allocations. We examine our allocation method using a factorial experimental design, and we conclude that our heuristic outperforms the utilization-equalization method which was used by at least one county in the 2008 presidential election.

*Index Terms*— Voting Queus, Simulation

# INTRODUCTION

Election administration is a service provided to the voting public. As with other service systems, waiting lines are non-value added activities and waiting time is viewed negatively. As discussed in Mebane (2005), waiting times to vote are directly correlated to voter turnout. As waiting times increase, more voters are forced to leave without having cast their ballots due to impatience and other time commitments. Thus, it is very important to design voting systems that result in voters waiting the least amount of time possible. Ideally, we would provide a sufficient quantity of voting machines such that voters would never have to wait to cast ballots. However, due to the expense of new voting machines such as direct-recording electronic

(DRE) machines (also known as “touch-screen” machines), election boards are limited in their ability to procure additional equipment.

Perhaps even more importantly, voting systems should provide equity, which means that we should not design systems that favor some voting groups (defined by geography, voting preference, etc.) by having shorter lines in some precincts than others. Such inequities have been a concern in recent elections. The Department of Justice investigated claims that the Board of Elections in Franklin County, Ohio, “systematically assigned fewer voting machines in polling places serving predominantly black communities as compared to its assignment of machines in predominantly white communities” during the 2004 election (Tanner 2005). While the Department of Justice ultimately found no evidence of systematic decisions to create voting inequities, their report does point to many factors, including specific measures of voter wait times and differences in voting patterns across precincts, which are typically not taken into account under current voting-machine allocation policies. Furthermore, Walter Mebane, Political Science Professor at the University of Michigan, has produced several studies criticizing the Department of Justice’s response to the issues in Franklin County. Professor Mebane concludes from his research, “The allocation of voting machines in Franklin County was clearly biased against voters in precincts with high proportions of African Americans” (Mebane 2006).

Determining an optimal voting-machine allocation is challenging and difficult to solve for several reasons. (1) Voters arrive randomly and according to non-stationary processes to polling locations. There are typically surges in voter arrivals during the morning, noon and evening times due to work schedules (Edelstein 2006). Moreover it is difficult to estimate voter turnout rates prior to Election Day because it depends on many uncontrollable variables (e.g., weather, composition of the voting ballot, etc.). (2) Voter queues may not reach steady state. Ohio law requires that the polls be open 13 hours, plus however much time is needed to accommodate voters waiting to vote at 7:30 pm. Given the limited amount of time that voting precincts are open, the voting queues may still be in a transient state. Such non-stationary arrivals and non-steady-state queues violate the fundamental assumptions of traditional queueing theory. (3) Actual voting scenarios involve considerable computational complexity. There are thousands of polling stations across Ohio and the input variables are stochastic. The result is a large-scale non-linear stochastic optimization problem. Thus, both building model and developing solution methods are challenging endeavors.

We model the voting process using a simulation model that allows us to employ non-stationary arrivals and non-steady state queues. We allocate voting machines to precincts using a greedy improvement heuristic. The objective in our machine allocation is to provide voter equity across precincts. The rest of the paper is arranged as follows. Section 2 provides a review of related literature. Section 3 introduces a performance metric for voter equity and discusses several analysis options for this problem. Section 4 describes the setup of the simulation model and the greedy improvement algorithm (GIA) implemented on the model. Section 5 systematically studies the performance of the simulation-based GIA through an experimental design. Section 6 presents conclusions and future work.

# Literature Review

There are relatively few papers that apply operations-research models to the voting-machine-allocation problem. However, this problem is closely related to queuing-model applications and resource-allocation problems that are common in operations research. Here we will mention only those papers that are most closely related to our application of voting- machine allocation or that reference solution method we use directly.

The only papers of which we are aware that apply operations research to the voting-machine-allocation problem are Edelstein (2006), Allen and Bernshteyn (2006a) and Allen and Bernshteyn (2006b). Edelstein (2006) and Allen and Bernshteyn (2006b) use simulation for their models. Using simulation allows these authors to consider some of the realistic complications in their models including voting-machine failures and non-stationary voter arrivals. However, neither paper explicitly considers voter equity in terms of maintaining equivalent waiting times across precincts. Allen and Bernshteyn (2006a) suggest using queueing models to measure voter waiting times for given machine-allocation policies and to improve allocation decisions. They use simple analytical queueing models to predict average waiting times for voters. Allen and Bernshteyn then suggest an optimization model that uses a minimax objective function to allocate voting machines. Specifically, they suggest allocating machines to minimize the maximum expected voter waiting time across all precincts. The minimax objective is designed to promote voter equity as we discuss above, but there are many other objectives that could be considered. Allen and Bernshteyn (2006a) also do not consider complicating issues such as non-stationary voter arrivals, machine failures, and specific differences in voting-time requirements due to differences in ballot lengths. Furthermore, the authors propose only simple greedy-heuristic solution methods for their models, which can produce significantly suboptimal policies.

There are several simpler methods used to allocate voting machines to precincts that have been used in previous elections. An intuitive and simple method of allocating voting machines used by many election boards is to allocate machines in proportion to the expected number of voters at each precinct (Edelstein 2006). This method ignores any direct models of queuing effects and differences between precincts. At least one county in Ohio used a utilization equalization allocation policy in the 2008 presidential election to allocate voting machines. This method enforces voter equity by equalizing the utilization of voting machines rather than equalizing waiting times of voters. Moreover, the utilization rate is obtained by traditional queuing theory, which assumes stationary arrivals and steady-state operating conditions.

# Analysis Options

## Performance Metric

Simply minimizing total expected waiting time across all precincts is insufficient as this may allow long voter waiting times in some precincts in order to decrease voter waiting time in other precincts. This is undesirable in an election process as we seek to provide equity to all voters so that no one particular group of voters is disadvantaged or disenfranchised.

However, there is no universal way to interpret “equity.” The ideal case is that the expected waiting time in queue at every precinct is the same. But it is generally not feasible to achieve this ideal situation. Therefore, the following metric (the average absolute differences of expected waiting times among precincts) can be used as a proxy for “equity:”

# Simulation Analysis

Use either SI (MKS) or CGS as primary units. (SI units are strongly encouraged.) English units may be used as secondary units (in parentheses). **This applies to papers in data storage.** For example, write “15 Gb/cm2 (100 Gb/in2).” An exception is when English units are used as identifiers in trade, such as “3½-in disk drive.” Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity in an equation.

The SI unit for magnetic field strength *H* is A/m. However, if you wish to use units of T, either refer to magnetic flux density *B* or magnetic field strength symbolized as µ0*H*. Use the center dot to separate compound units, e.g., “A·m2.”

# Experimental Design and Results

## Figures and Tables

Large figures and tables may span both columns. Place figure captions below the figures; place table titles above the tables. If your figure has two parts, include the labels “(a)” and “(b)” as part of the artwork. Please verify that the figures and tables you mention in the text actually exist. **Please do not include captions as part of the figures. Do not put captions in “text boxes” linked to the figures. Do not put borders around the outside of your figures.** Use the abbreviation “Fig.” even at the beginning of a sentence. Do not abbreviate “Table.” Tables are numbered with Roman numerals.

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Figure axis labels are often a source of confusion. Use words rather than symbols. As an example, write the quantity “Magnetization,” or “Magnetization *M*,” not just “*M*.” Put units in parentheses. Do not label axes only with units. As in Fig. 1, for example, write “Magnetization (A/m)” or “Magnetization (Am−1),” not just “A/m.” Do not label axes with a ratio of quantities and units. For example, write “Temperature (K),” not “Temperature/K.”

Multipliers can be especially confusing. Write “Magnetization (kA/m)” or “Magnetization (103 A/m).” Do not write “Magnetization (A/m) × 1000” because the reader would not know whether the top axis label in Fig. 1 meant 16000 A/m or 0.016 A/m. Figure labels should be legible, approximately 8 to 12 point type.

## References

Number citations consecutively in square brackets [1]. The sentence punctuation follows the brackets [2]. Multiple references [2], [3] are each numbered with separate brackets [1]–[3]. When citing a section in a book, please give the relevant page numbers [2]. In sentences, refer simply to the reference number, as in [3]. Do not use “Ref. [3]” or “reference [3]” except at the beginning of a sentence: “Reference [3] shows ... .” Please do not use automatic endnotes in *Word*, rather, type the reference list at the end of the paper using the “References” style.

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Define abbreviations and acronyms the first time they are used in the text, even after they have already been defined in the abstract. Abbreviations such as IAENG, SI, ac, and dc do not have to be defined. Abbreviations that incorporate periods should not have spaces: write “C.N.R.S.,” not “C. N. R. S.” Do not use abbreviations in the title unless they are unavoidable (for example, “IAENG” in the title of the article).

## Equations

Number equations consecutively with equation numbers in parentheses flush with the right margin, as in (1). First use the equation editor to create the equation. Then select the “Equation” markup style. Press the tab key and write the equation number in parentheses. To make your equations more compact, you may use the solidus ( / ), the exp function, or appropriate exponents. Use parentheses to avoid ambiguities in denominators. Punctuate equations when they are part of a sentence, as in

 (1)

Be sure that the symbols in your equation have been defined before the equation appears or immediately following. Italicize symbols (*T* might refer to temperature, but T is the unit tesla). Refer to “(1),” not “Eq. (1)” or “equation (1),” except at the beginning of a sentence: “Equation (1) is ... .”

## Other Recommendations

Use one space after periods and colons. Hyphenate complex modifiers: “zero-field-cooled magnetization.” Avoid dangling participles, such as, “Using (1), the potential was calculated.” [It is not clear who or what used (1).] Write instead, “The potential was calculated by using (1),” or “Using (1), we calculated the potential.”

Use a zero before decimal points: “0.25,” not “.25.” Use “cm3,” not “cc.” Indicate sample dimensions as “0.1 cm × 0.2 cm,” not “0.1 × 0.2 cm2.” The abbreviation for “seconds” is “s,” not “sec.” Do not mix complete spellings and abbreviations of units: use “Wb/m2” or “webers per square meter,” not “webers/m2.” When expressing a range of values, write “7 to 9” or “7-9,” not “7~9.”

A parenthetical statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.) In American English, periods and commas are within quotation marks, like “this period.” Other punctuation is “outside”! Avoid contractions; for example, write “do not” instead of “don’t.” The serial comma is preferred: “A, B, and C” instead of “A, B and C.”

If you wish, you may write in the first person singular or plural and use the active voice (“I observed that ...” or “We observed that ...” instead of “It was observed that ...”). Remember to check spelling. If your native language is not English, please get a native English-speaking colleague to carefully proofread your paper.

# Conclusions and Future Work

The word “data” is plural, not singular. The subscript for the permeability of vacuum µ0 is zero, not a lowercase letter “o.” The term for residual magnetization is “remanence”; the adjective is “remanent”; do not write “remnance” or “remnant.” Use the word “micrometer” instead of “micron.” A graph within a graph is an “inset,” not an “insert.” The word “alternatively” is preferred to the word “alternately” (unless you really mean something that alternates). Use the word “whereas” instead of “while” (unless you are referring to simultaneous events). Do not use the word “essentially” to mean “approximately” or “effectively.” Do not use the word “issue” as a euphemism for “problem.” When compositions are not specified, separate chemical symbols by en-dashes; for example, “NiMn” indicates the intermetallic compound Ni0.5Mn0.5 whereas “Ni–Mn” indicates an alloy of some composition NixMn1-x.

Acknowledgment

The preferred spelling of the word “acknowledgment” in American English is without an “e” after the “g.” Use the singular heading even if you have many acknowledgments. Avoid expressions such as “One of us (S.B.A.) would like to thank ... .” Instead, write “F. A. Author thanks ... .” **Sponsor and financial support acknowledgments are placed in the unnumbered footnote on the first page, not here.**

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1. Manuscript received June XX, 20XX; revised July XX, 20XX. (Write the date on which you submitted your paper for review.) This work was supported in part by the U.S. Depart­ment of Com­merce under Grant BS123456 (sponsor and financial support acknowledgment goes here). Paper titles should be written in uppercase and lowercase letters, not all uppercase. Avoid writing long formulas with subscripts in the title; short formulas that identify the elements are fine (e.g., "Nd–Fe–B"). Do not write “(Invited)” in the title. Full names of authors are preferred in the author field, but are not required. Put a space between authors’ initials.

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