Omega 57 (2015) 230–237

Contents lists available at ScienceDirect

Omega

journal homepage: www.elsevier.com/locate/omega

A robust voting machine allocation model to reduce extreme waiting ☆

Muer Yang [a], Xinfang (Jocelyn) Wang [b,*], Nuo Xu [c]

[a] Department of Operations and Supply Chain Management, Opus College of Business, University of St. Thomas, Saint Paul, MN 55105, United States
[b] Department of Logistics and Supply Chain Management, College of Business Administration, Georgia Southern University, Statesboro, GA 30460, United States
[c] Department of Management, Information Systems & Quantitative Methods, School of Business, University of Alabama, Birmingham, AL 35294, United States

ARTICLE INFO

Article history:
Received 8 April 2014
Accepted 6 May 2015
Communicated by: Prof. B. Lev
Available online 22 May 2015

Keywords:
Robust optimization
Resource allocation
Voting operations
Public service

ABSTRACT

Despite the fact that in the 2012 presidential election, two-thirds of voters waited less than 10 min and a mere 3% waited longer than an hour to cast their ballots, media accounts of excruciating waits have left a misleading impression on the general public. At the root of the problem is the allocation of voting machines based on efficiency as measured by average waiting time. This method does not account for the damaging consequences of the rare events that cause extremely long waits. We propose an extreme-value robust optimization model that can explicitly consider nominal and worst-case waiting times beyond the single-point estimate commonly seen in the literature. We benchmark the robust model against the published deterministic model using a real case from the 2008 presidential election in Franklin County, Ohio. The results demonstrate that the proposed robust model is superior in accounting for uncertainties in voter turnout and machine availability, reducing the number of voters experiencing waits that exceed two hours by 61%.

1. Introduction

In reaction to the 2000 United States presidential election controversy, where almost 2 million ballots were disqualified, Congress passed the Help America Vote Act (HAVA) in 2002. It mandates replacement of punch-card or lever machines with newer voting technologies, such as optical-scan voting systems and direct-recording electronic (DRE) machines. However, the transition has created unforeseen problems. For instance, in the 2004 US presidential election, some voters waited for more than 10 h to cast their ballots [1]. Since then, incidents of long lines and waiting times, even voter disenfranchisement, were reported in the 2006, 2008, and 2010 elections [2–5].

Long waiting times result from a number of factors associated with electronic voting machines. Compared to traditional ballots, DRE machines result in longer average voting times because their multi-page display does not allow voters to easily bypass any races or issues on the ballot. New technologies are more prone to breakdown and more challenging for election workers to repair. However, the primary problem that Boards of Elections face is an inadequate number of available voting machines [6] and the associated challenges in assigning them under the uncertainty of voter turnout and machine unavailability (long-term fraction of the time machines are not working). The current voting system in the United States allows each state, and even each county within a state, to determine its own policy and method for elections. Voters in a county are generally divided into geographic regions known as voting precincts. With the passage of HAVA, determining how many voting machines are allocated to each precinct has become one of the most critical decisions made by Election Boards at the county level.

The common practice is to assign a number of machines proportional to a precinct's registered voters [7]. This approach is problematic. It does not account for several sources of variation in voting process among precincts: voter turnout rates are known to vary from year-to-year and across precincts; ballot length is often different among precincts; and voting machine failures range from a paper jam to a computer system crash can also cause further variation. In the 2012 presidential election, many Florida voters reportedly had to wait three to four hours, and some waited as long as seven hours, to cast early ballots [8]. In his acceptance speech, President Obama acknowledged, “(voters) waited in line for a very long time,” adding, “by the way, we have to fix that” [9]. Media attention to long lines at polling stations left the general public with the impression that they are prevalent. However, according to a recent empirical study [10], two-thirds of voters in that election waited less than 10 min to vote; a mere 3%

☆This manuscript was processed by Associate Editor Gautam.

* Corresponding author. Tel.: +1 912 478 0523; fax: +1 912 478 1835.
E-mail addresses: yangmuer@stthomas.edu (M. Yang), xfwang@georgiasouthern.edu (X.(Wang), nuoxu@uab.edu (N. Xu).

http://dx.doi.org/10.1016/j.omega.2015.05.003
0305-0483/© 2015 Elsevier Ltd. All rights reserved.

waited more than an hour. Nevertheless, voters were seriously discouraged by relatively low-frequency events.

US citizens have a constitutional right to equal access to voting facilities, including the right to vote within a reasonable time [11]. Ury v. Santee 303 F. Supp. 119 (1969) found that voters "required to wait for periods of two to four hours to cast their ballots" were "effectively deprived of their right to vote" and a new election was ordered [12]. The 2008 Survey of the Performance of American Elections [13] reported that up to 2.6 million people were disenfranchised by long lines in the 2008 presidential election, which may have influenced the outcome. In Rio Rancho, New Mexico, a lawsuit was filed against the Sandoval County Clerk and her employees because thousands were "effectively prevented from voting due to the long lines and long delays (over five hours) for voters in Rio Rancho on Election Day" in 2012 [11].

This "sting-in-the-tail" suggests that the current practice of minimizing the single point estimate of average waiting time is insufficient. To better prepare for extremely long waits, which, however rare, have high impact, we developed and evaluated an extreme-value robust optimization model in the framework of Bertsimas and Sim [14]. The robust model explicitly considers the uncertainty in key parameters by capturing their nominal and worst-case (maximum) values, not just the single-point estimate seen in the literature. In addition, our model can offer different degrees of robustness by specifying a single parameter and can be easily solved using off-the-shelf software, such as AMPL/CPLEX.

The remainder of the paper is organized as follows. Section 2 reviews the literature. In Section 3, we describe our derivation of the robust model. Section 4 compares the performance of the proposed robust model and the deterministic model using Franklin County data from the 2008 presidential election. Section 5 presents conclusions and directions for future research.

2. Literature review

The machine allocation problem can be divided into two sequential tasks. The first involves studying and modeling waiting times, factoring in machine unavailability, voter turnout rate, ballot length, arrival patterns, etc. The two common approaches are closed-form queuing formulas, which provide exact values for key performance measures but impose strict assumptions (e.g., steady-state queues, stationary arrivals) [15], and simulation models, which can accommodate complex queuing systems but make inexact estimates and require intensive computational effort [16]. The second task takes the outputs from the first (e.g., average waiting time) and applies mathematical models to allocate machines among precincts to optimize a specified objective function of interest.

In the late 1970s, Grant applied simulation and linear programming to reduce voters' average waiting time. He used the results to devise a worksheet [17] that would enable nontechnical election officials to estimate the number of machines required for each precinct to meet certain performance criteria, such as a wait of less than three minutes for 90% of voters, by entering estimates of such simulation parameters as turnout rate, discrete mean-voting time, and arrival rate change. Grant also developed an iterative procedure and a linear programming application to allocate machines among precincts with an insufficient number of machines [18,19].

Allen and Bernshteyn [7] found that variations in service time affected voters' waiting times to a greater degree. Assuming a fixed number of machines, they formulated an optimization problem with an objective function of minimizing the maximum average waiting time as calculated from an $M/M/s$ queuing formula. It was solved by a greedy heuristic. In addition to service time, machine failures and downtimes can also be a reality of Election Day. Such issues led to significant voting impairment during the 2010 elections in New York, prompting mayor Michael Bloomberg to call the event "a royal screw-up" [5]. Allen and Bernshteyn [20] later extended their work by using simulations to study machine breakdowns and repair times with simple estimated-frequency tables and further proposed to use the simulation and a pre-specified performance measure threshold to determine the number of machines allocated to each precinct. They also defined a new set of objective functions, including the expected number of polling locations to have average waits longer than a threshold value besides the commonly used average waiting time, to evaluate the simulation results.

Following a similar simulation approach, Edelstein [6] focused on the issue of estimating the maximum number of voters a machine can serve without creating a long queue, taking "heavy traffic periods" into consideration. The author developed a heuristic called the "queue stop rule" and estimated that 130 voters per machine would allow a smooth election process, where the probability of exceeding a 15-minute wait is less than 0.1%. Since Maryland law specifies 200 voters per machine, the author suggested supplementary paper ballots as the only practical solution to the lack of capacity.

Yang et al. [21] represent the most advanced effort in this stream of research. They set the machine-allocation problem in the framework of resource-allocation problems to introduce the concept of equity. Contrary to average waiting time, the efficiency measure used by most researchers, they formally introduced the equity metric–a range of waiting times—as a more appropriate objective function [21]. Assuming specific voting time and arrival process distributions, a fixed turnout rate, and 100% machine availability, they simulated voting queues to estimate waiting times (e.g., order statistics of waiting times). The results were fed into an integer programming model, and simulation-optimization techniques were used to address sampling errors in the estimated waiting times while searching for the optimal allocation plan. Although tremendous effort was spent on simulating waiting times, the actual waiting time used in the machine allocation optimization model is a point estimate based on assumptions about the input parameters. Such a deterministic approach seriously jeopardized the validity of their optimal allocation plan in face of violation of assumptions on input parameters in reality. Yang et al. [22] continued the deterministic approach to evaluate multiple voting machine allocation methods and concluded that the model using simulated waiting times outperformed methods using the queuing formula. They related the voting machine allocation problem to the generalized assignment problem, which assigns n jobs to m agents to minimize the total assignment cost. They suggested operational changes in the voting process that might reduce waiting times without requiring more machines.

Although the foregoing research was developed using different modeling techniques and objectives shifted from efficiency to equity, few studies mention low-frequency, high-impact long waits and they are never fully examined. In light of this neglect, we propose a robust optimization model for allocating voting machines among precincts that directly addresses the uncertainty-induced extreme waiting time [14]. We do not address how to *estimate* uncertain waiting time since Yang et al. [21], among others, have thoroughly studied the question. Instead, we focus on a gap in the current literature, i.e., how to *incorporate* uncertain waiting time into the allocation model to reduce the number of voters experiencing extreme waits, once they are being estimated from the simulation procedures.

Robust optimization is an appropriate technique for modeling voting machine allocation because it is designed to hedge against extreme values of uncertain parameters [23,24]. The exact distribution